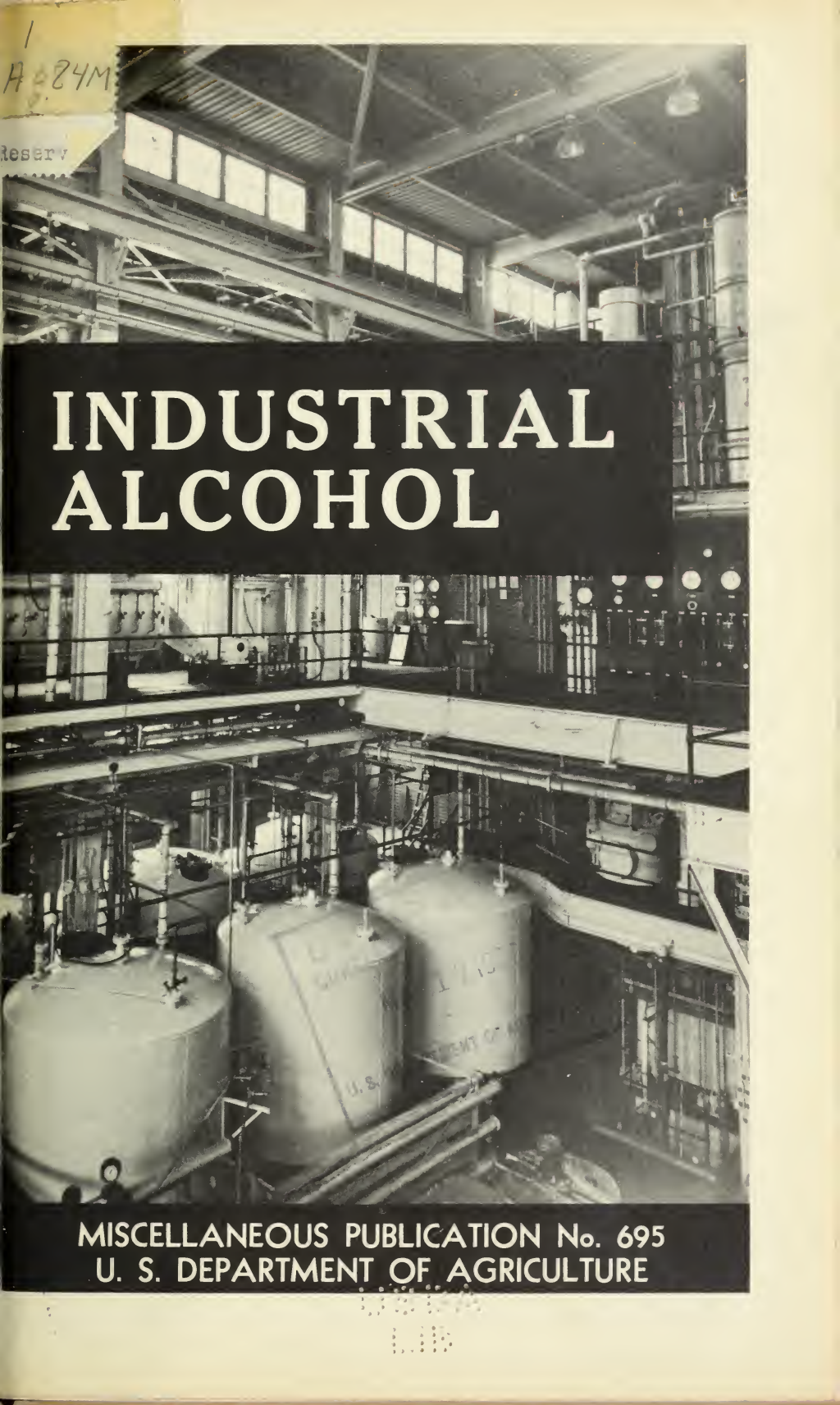


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# INDUSTRIAL ALCOHOL

MISCELLANEOUS PUBLICATION No. 695  
U. S. DEPARTMENT OF AGRICULTURE

## PREFACE

A number of publications on various phases of alcohol production use, technology, and economics have been issued by the United States Department of Agriculture during the past four decades. These publications originated principally in the scientific research agency that has been, successively, the Division of Chemistry (until 1901), the Bureau of Chemistry (1901-27), the Bureau of Chemistry and Soils (1927-38), the Bureau of Agricultural Chemistry and Engineering (1938-43), and presently the Bureau of Agricultural and Industrial Chemistry of the Agricultural Research Administration.

Earlier publications on alcohol, by H. W. Wiley and his associates, were issued by the Bureau of Chemistry in 1906-10, shortly after the passage of the industrial alcohol act. Subsequently a pamphlet entitled "Information on Industrial Alcohol," by W. W. Skinner, was issued in 1922. This was intended for use in replying to general inquiries on alcohol. Because of wide and continued public demand for this type of information, the pamphlet was revised by staff members of the Bureau of Chemistry and Soils and reissued in May 1936.

The major changes that have taken place in the alcohol industry in the past decade have caused former publications to become obsolete rapidly, and frequent revisions of texts have been necessary to reflect technological and other changes. A third and expanded revision of the 1936 publication was made by P. Burke Jacobs, and issued as Bureau of Chemistry and Soils Circular MC-22 in January 1938. Continued demand necessitated a further expanded revision by Mr. Jacobs, which was issued in March 1943 as Bureau of Agricultural and Industrial Chemistry Circular AIC-3, entitled "Industrial Alcohol." All of these former publications are out of print.

In the present publication it has been the objective to include a wide variety of information on chemical, technological processing, and industrial aspects. Data from other publications on alcohol<sup>1</sup> by Mr. Jacobs have been incorporated herein, so as to combine essential information comprehensively in one general purpose text.

<sup>1</sup> In particular, Motor Fuels from Farm Products, Misc. Pub. 327; Alcohol from Agricultural Commodities, AIC-95; and Industrial Alcohol, AIC-3. Sources of additional information are given on p. 94.



# UNITED STATES DEPARTMENT OF AGRICULTURE

MISCELLANEOUS PUBLICATION NO. 695

WASHINGTON, D. C.

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## INDUSTRIAL ALCOHOL

### A Study of the Technology, Production, and Uses of Alcohol in Relation to Agriculture

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## ETHYL ALCOHOL

## ORIGIN AND CHEMISTRY

Ethyl alcohol, commonly known as "grain" alcohol and formerly designated by many titles, such as "spirits of wine," "eau de vie," etc., has been used by the human race since the dawn of history. It has been perhaps the most universally known chemical compound manufactured. Originally produced by the spontaneous fermentation of sugars, it was utilized unknowingly by ancient races who were aware of its intoxicating effect, and who evolved methods of producing many types of alcoholic beverages.

The Arabs and the Romans learned to extract and partially concentrate the spirit from wine or from other fermented materials in crude stills. This more concentrated spirit actually represented the first form of industrial alcohol (i. e., for other than beverage use) and was employed in the preparation of perfumes, cosmetics, and as a medicinal agent. Later civilizations improved upon the distillation and purification processes. As the sciences of chemistry and medicine developed, ethyl alcohol found increasing use as a chemical agent, an ingredient, or a raw material for the formation of other compounds, and as a therapeutic aid. In addition, its world-wide use as an essential ingredient in various beverages continued, so that the manufacture of the many diverse types of alcoholic products eventually became specialized industries.

Chemically, ethyl alcohol (ethanol) is one member of a series of related substances (alcohols), other commonly known members of which include "wood" alcohol (methanol), isopropyl alcohol (isopropanol), butyl alcohol (butanol), and amyl alcohol (pentanol). These compounds all have a definitely related chemical constitution or structure, but differ by the number of carbon atoms in each— $C_1$ =methanol,  $C_2$ =ethanol,  $C_3$ =propanol,  $C_4$ =butanol,  $C_5$ =pentanol, and so on. Various (lower carbon) members of the family have physical properties of considerable similarity, and can be substituted for each other to a considerable extent in certain uses. The lower carbon alcohols ( $C_1$  to  $C_3$ ) are liquids and are completely water soluble; the slightly higher carbon members ( $C_4$  to  $C_9$ ) are liquids of progressively decreasing water solubility and increasingly oily character; and the higher ( $C_{10}+$ ) carbon compounds are solids insoluble in water.

These alcohols are produced commercially from different raw materials and by different methods. Methanol originated commercially from the destructive distillation of wood (hence its former name) although now it principally is produced synthetically from gases. Likewise, ethanol, isopropanol, and butanol now largely are chemically synthesized from certain hydrocarbon gases such as occur in natural gas or in the gases evolved from petroleum refining. Of the alcohol series, only ethanol and butanol (and some pentanol) are produced commercially in significant amounts by fermentation processes based on sugar or starch (carbohydrates). All of the lower carbon members of the family now are produced commercially to a large extent by synthesis.

Although ethyl alcohol now is produced from many types of raw materials and by diverse methods, until about 1929 it was produced

commercially in the United States only by the fermentation of starch or sugar. In recent years it has been losing some of its former industrial importance because of competition from methanol, isopropanol, butanol, and other alcohols or derivatives thereof; legal restrictions surrounding its use; the relative costs of production; and its relative value for specific uses. However, because of its manifold uses and applications in industry, commerce, medicine, and the home, both as a chemical agent and as a beverage ingredient, ethyl alcohol continues to be a very important chemical commodity. It is marketed in many forms, ranging from pure and practically anhydrous alcohol to solutions or mixtures containing various (and often relatively small) percentages of spirit.

### TAXATION AND LEGAL DEFINITION

For several centuries it has been customary for governments to levy a tax on solutions and distillates containing ethyl alcohol, thus raising revenue while achieving a form of penalization or restraint upon the use of intoxicating beverages. In the United States, early Congresses levied taxes on rum and whisky (the latter causing the "Whisky Rebellion" of 1792). After the Civil War the taxation system was greatly expanded. With the increasing production and availability of more highly purified spirits suitable for use as a chemical agent or as raw material in industry (i. e., nonbeverage use) during the past century, it gradually became evident that the imposition of a *beverage* tax upon a chemical commodity introduced unnecessary costs into many manufacturing operations.

In 1906, following the earlier example of France, Germany, Great Britain,<sup>2</sup> and other nations, Congress passed an act, known as the Denatured Alcohol Act, permitting the production and sale of tax-free alcohol for industrial purposes but imposing certain restrictions on such use. The addition of denaturing substances was authorized as a form of preventative against the subsequent illegal recovery or use of such alcohol as a beverage, since all alcoholic beverages were, and still are, subject to taxation. In a supplemental act of March 2, 1907, the original legislation was broadened.

In the United States, until 1919 (October 28) all distilled ethyl alcohol, whether for industrial or beverage use, was produced in distilleries. Passage of the 18th Amendment, effective January 16, 1920 (and National Prohibition Act) caused a separation of product types, creating industrial alcohol (so-called Title III) plants, which produced concentrated alcohol for industrial and scientific uses, the production of alcoholic distillates for beverage uses being limited to distilleries. This was effected under Title III of the legislation. Upon passage of the Twenty-first amendment, effective December 5, 1933 (and Repeal Act) the provisions of Title III were continued in force.

The industrial alcohol industry thus created is legally separate and distinct from the beverage alcohol industry. Because of the tax aspect, however, *all* alcohol production industries in the United States

<sup>2</sup> Denatured alcohol, usually referred to abroad as "methylated spirit," became available, tax-free, for industrial use as follows: Great Britain 1855, Netherlands 1865, France 1872, Germany about 1887, Austria 1888, Italy 1889, Sweden 1890, Norway 1891, Switzerland 1893, and Belgium 1896.



are subject to the revenue laws relating to alcoholic liquors. These laws are administered by the Alcohol Tax Unit, Bureau of Internal Revenue, United States Department of the Treasury. Hence, the alcohol industries are controlled and regulated by Federal rules and regulations originating in the Alcohol Tax Unit. No ethyl alcohol may be produced or sold, in any form, without the permission and supervision of this agency (26, 29).<sup>3</sup>

Alcohol produced in industrial alcohol plants for tax-free industrial purposes usually is marketed as denatured. Denaturing signifies that certain chemical agents have been added, in accordance with the regulations, to render such alcohol relatively unfit for human consumption. However, relatively pure (undenatured) alcohol also is marketed by the industrial alcohol industry (usually at 95-percent concentration), and such alcohol may be sold as tax-free or tax-paid, depending on use. Thus, straight alcohol for hospitals, scientific, or Government use is tax-free, while similar alcohol used in foods, flavorings, or pharmaceuticals for human internal use is taxed. Straight alcohol is used also as an added component of certain types of beverage spirits (as so-called neutral spirits) in the manufacture of blended whiskies (alcohol-water dilutions of distilled whisky), and also in the manufacture of gin, cordials, and the like. When thus used for ultimate beverage purposes, such alcohol ordinarily is considered statistically as industrial alcohol, as produced,<sup>4</sup> but as distilled spirits (beverage alcohol), as utilized, and it bears the same tax as distilled spirits.<sup>5</sup>

Ethyl alcohol, although historically produced by fermentation, now also is produced synthetically, or as a byproduct of certain industrial chemical operations. Alcohol of such synthetic or chemical origin is classed as industrial alcohol without distinction from fermentation

<sup>3</sup> Italic numbers in parentheses refer to Literature Cited, page 92.

<sup>4</sup> Since 1936, the manufacture of a product identical with 95-percent straight alcohol has been permitted in distilleries, for subsequent use as blending spirits. However, this product could be sold outside the distillery only if reduced below 160 proof. Under statutory amendments accomplished by the acts of January 24 and March 27, 1942, such alcohol for the present can be marketed as 190 proof. However, such product is defined as (high proof) spirits, and not as alcohol. Such spirit subsequently may be designated as alcohol after transfer from distillery to an industrial alcohol plant, industrial alcohol warehouse, or denaturing plant, since it is practically identical with the straight alcohol from an industrial alcohol plant.

<sup>5</sup> At present, the tax on beverage alcohol is \$9 per proof (or tax) gallon. A proof gallon represents 1 U. S. standard wine gallon (231 cubic inches volume) containing 50 percent of alcohol by volume (42.5 percent by weight). There are 3.3065 pounds of pure (100 percent) alcohol in a proof gallon. For tax purposes the alcohol content of any mixture, at any percentage, is always computed to proof gallon basis and so reported (exclusive of denatured alcohol), regardless of the original volumetric gallonage represented by the particular mixture. The designated "proof" of any alcoholic liquid is twice the percentage of alcohol (by volume) present. One gallon of 95-percent (or 190 proof) alcohol, therefore, represents 1.9 proof gallons. All industrial alcohol must be 160 proof or over. This tax is rebated, in part (\$6), when the alcohol is used for special purposes (food flavorings, pharmaceuticals, etc.). British nations use a different "proof" basis (49.24 percent, by weight) and employ a different degree system. Also, they use the Imperial gallon, which is 1.2 American gallons. The term "proof" is derived from an old chemical evaluation test used to determine alcoholic content, probably several centuries ago. Proof alcohol represented that concentration at which gunpowder would ignite, when saturated with the liquid. Liquids more dilute were "under proof," conversely, "over proof." These terms still are employed in Great Britain.

alcohol, and it now represents a very significant part of the total production of ethyl alcohol. Without adhering too closely to the wording of the regulations of the Treasury Department, the term "industrial alcohol" may be defined for practical purposes as including all pure (or undenatured) alcohol however derived (29, 30), and all mixtures of alcohol with chemical denaturing agents.

In the manufacture of alcohol for industrial uses, high alcohol concentration and relative purity are stressed. Such production necessitates careful supervision over raw materials and manufacturing processes to obtain adequate yields and acceptable quality, but great latitude as to raw materials exists. Denaturing agents used must be of approved type.

Alcohol for beverage use falls into a different category. Alcoholic beverages are of two general types, *distilled* and *undistilled*. Whisky, brandy, and rum are examples of the type produced by distillation. They are designated generally as distilled spirits. Wine, beer, and liqueurs (ordinarily), however, represent types that are not distilled. None of these products are classed as industrial alcohol, although they contain alcohol and, in the case of distilled spirits, are produced by a fermentation and distillation process similar to that employed for (fermentation) industrial alcohol. Whisky, brandy, and rum, while consisting principally of ethyl alcohol and water (usually 50 percent alcohol or less), contain, in addition, small quantities of naturally occurring congeneric substances that impart characteristic flavors and bouquets which are lacking in mixtures of pure alcohol and water. Types of beverage products are related to the character of the raw material used (whisky from grain, brandy from fruit, rum from molasses, etc.). Such spirituous beverages are produced under special regulations and conditions (26, 28, 31), and in the case of distilled spirits, usually are distilled at somewhat lower concentrations than industrial alcohol. They are sold practically in the form produced (water additions only), with principal emphasis on character (taste or bouquet) rather than on alcohol concentration. To govern the composition and content of the congeneric substances in the several legally identified types of beverage spirits, use of specific raw materials is mandatory, and specialized steps in the process of manufacture are essential.

Malt beverages (beer) and wines, fermented products of grain or fruit, respectively, ordinarily are not distilled, but are used as originally produced. Their alcohol concentrations are relatively low, (beer, 3 to 5 percent; wines, 12 to 20 percent). Raw materials which can be used are specifically limited by regulations (35, 27). So-called fortified wines, such as muscatel, port, sherry, and the like contain added brandy, a distilled spirit. (This brandy prevents subsequent fermentation and avoids the possibility of the sugar in sweet wines being converted into alcohol.) Thus, fortified wines have a high alcoholic content (20 percent). In contrast, light table wines such as burgundy, chianti, claret, sauterne, zinfandel, etc., usually contain only about 12 percent of alcohol, which is the usual maximum obtainable in straight fermentation. Gin and liqueurs are decoctions of various flavoring materials in straight (diluted) alcohol, and are not produced by fermentation. These products are not distilled (excepting some types of gin).



## THE ALCOHOL-DISTILLATION INDUSTRIES

The manifold applications of alcohol can be differentiated into two general fields: (a) chemical and physical uses, and (b) beverage uses. Four practically separate industries have been evolved to supply these requirements—industrial alcohol plants, distilleries, wineries, and breweries, the last three of these being wholly beverage producers. However, in usual practice, only the first two mentioned actually separate and recover alcohol by distillation.

From a production standpoint, a general differentiation of the alcohol distillation industries can be made. Practically all alcohol produced for chemical, physical, or manufacturing uses is originally recovered at concentrations of 95 percent by volume or higher and in a relatively pure state, regardless of the subsequent use or form in which sold. Minimum allowable concentration is 80 percent by volume (160 proof). All alcohol produced at such concentration (and degree of purity) is known as industrial alcohol<sup>6</sup> regardless of source material, and is produced under and controlled by specific regulations, at industrial alcohol plants (28, 29). In contrast, ethyl alcohol recovered by distillation for use only as a beverage (whisky, brandy, rum) ordinarily is handled in concentrations not exceeding 80 percent by volume (160 proof) in a semipurified state only, and is produced and used under distinctly separate legal regulations (26, 28, 31). and source materials are specifically limited. These production plants are known as registered distilleries.

The simple industry classification thus indicated actually is quite complicated. When suitable bonds protecting the Government against tax loss through illegal diversion of alcohol are filed and permits obtained, in certain instances registered distilleries may be operated alternatively as industrial alcohol plants or vice versa for definite periods, losing one legal identity and assuming another temporarily. In other instances, legally independent and separate industrial alcohol plants and (beverage) distilleries may be parts of one common parent organization, sometimes occupying adjoining premises for simultaneous operations. Some industrial alcohol plants may be subdivided as to raw material or equipment use, and occasionally such plants may produce acetone and butanol also, under part-time or part-plant operations, since the plant equipment is capable of such dual use. At present the production of malt sirups in industrial alcohol plants is permitted temporarily by congressional resolutions of 1946–48.

Fruit distilleries may recover alcohol by distillation from byproducts of wine production, and such alcohol may be used to fortify wines, or sold as brandy. Consequently, many fruit distilleries are identical in ownership or are operated in conjunction with wineries. Fruit distilleries also might operate as grain distilleries or vice versa, under suitable bonding and permit arrangements. It should be emphasized that each legal entity, in all these instances, must be physically separate and distinct and covered by separate bonds to cover conceivable revenue losses.

Furthermore, in the production of de-alcoholized malt liquor certain amounts of alcohol may be recovered. Rum may be denatured for

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<sup>6</sup> See footnote 4, page 4.

industrial (nonbeverage) use. Rectifying plants may rehandle alcohol produced in industrial alcohol plants or spirits produced in distilleries to produce new beverage compounds (rectified spirits, cordials, etc.). These plants physically might be located contiguous to a distillery but nevertheless must have a separate legal entity. An additional "rectifying" tax must be paid in this instance. Denatured alcohol actually is not made in industrial alcohol plants, which make only straight alcohol, but in denaturing plants which are legally separate from the alcohol plants, although perhaps located on adjoining but separately bonded premises. In addition, certain chemical plants which are users but not producers of alcohol may be allowed to recover denatured alcohol for reuse in their own processes. Therefore, the industrial aspects are quite complex when considered in detail.

The following discussion considers alcohol only in its relatively concentrated form, hence is primarily concerned with the industrial alcohol industry. However, certain aspects of the distilled spirits industry are considered also, where applicable, since this industry is closely related in many ways.

### HISTORY OF PRODUCTION

The usual consumption of domestically produced alcohol in the United States in various channels for chemical, physical, or manufacturing use, immediately prior to 1939, averaged about 115 million (wine) gallons annually. This was marketed either as pure alcohol, completely denatured alcohol,<sup>7</sup> or as specially denatured alcohol. Certain quantities (13 to 19 million gallons) of the undenatured alcohol were used annually for purposes which might be considered as relatively nonindustrial, both as tax-free and tax-paid alcohol, much of which subsequently was transferred to and used by the beverage industry for blending of spirituous liquors. (This can be considered as representing a special use of industrial alcohol, although statistically included in such production.) Production of industrial alcohol is given in table 1, and the production of distilled spirits is shown in table 2. In these tables the production of high-proof spirits in distilleries has been separated and included in table 1 (column 2) to show its effective relationship to industrial alcohol. Data on distilled-spirits production in table 2 (column 1) are correspondingly reduced. Total withdrawals of alcohol as tax-paid, for both industries, are combined in table 1 (column 3). Such alcohol essentially finds use as blending spirits,<sup>8</sup> although from 5 to 7 million proof gallons annually may find other use.

<sup>7</sup> These designations refer to two general classes of denatured alcohol (30). Completely denatured alcohol contains added chemicals of types and in amounts sufficient to prevent recovery of ethyl alcohol therefrom in a purity suitable for beverage use, by any reasonable method. It, therefore, can be marketed with little restriction. Specially denatured alcohol represents partial denaturation only, usable alcohol possibly being recoverable therefrom. Hence specially denatured alcohol ( $\pm 57$  formulas) is sold only on a Federal permit basis, for authorized specific uses, and handling is subject to control and supervision.

<sup>8</sup> Blending alcohol use perhaps may be checked more closely by consulting tables showing alcohol used for rectification, issued by the Alcohol Tax Unit.

TABLE 1.—*Production of industrial alcohol and high-proof spirits, showing tax-paid and tax-free use*

Fiscal year	Production as alcohol (in industrial alcohol plants)	Production as high-proof spirits (in distilleries)	Total used as tax paid <sup>1</sup> (from industrial alcohol plants and distilleries)	Percent tax paid of total production	Used for denaturing	Denatured alcohol produced as—	
						Specially denatured	Completely denatured
	<i>Proof gallons</i>	<i>Proof gallons</i>	<i>Proof gallons</i>		<i>Proof gallons</i>	<i>Wine gallons</i>	<i>Wine gallons</i>
1920	<sup>2</sup> 18, 933, 551	<sup>2</sup> 79, 502, 619	22, 639, 355	23. 0	46, 640, 949	15, 307, 947	13, 528, 403
1921	85, 068, 776	( <sup>3</sup> )	26, 275, 969	30. 9	39, 343, 251	9, 996, 230	12, 392, 595
1922	79, 906, 101	( <sup>3</sup> )	16, 391, 490	20. 5	61, 117, 444	17, 152, 224	16, 193, 524
1923	122, 402, 850	( <sup>3</sup> )	10, 763, 613	8. 76	109, 519, 332	30, 436, 913	27, 128, 230
1924	135, 897, 726	( <sup>3</sup> )	9, 382, 302	6. 9	125, 318, 323	33, 085, 292	34, 602, 004
1925	166, 165, 518	( <sup>3</sup> )	8, 547, 518	5. 13	152, 254, 939	34, 824, 303	46, 983, 970
1926	202, 271, 670	( <sup>3</sup> )	8, 801, 399	4. 36	195, 480, 934	39, 494, 444	65, 881, 442
1927	184, 323, 017	( <sup>3</sup> )	8, 253, 512	4. 47	173, 570, 104	39, 354, 933	56, 093, 748
1928	169, 149, 905	( <sup>3</sup> )	8, 675, 717	5. 13	161, 362, 455	45, 451, 424	46, 966, 601
1929	202, 616, 750	( <sup>3</sup> )	8, 892, 513	4. 4	186, 045, 935	54, 623, 207	53, 296, 717
1930	193, 823, 717	( <sup>3</sup> )	8, 251, 274	4. 26	185, 000, 827	47, 713, 468	59, 063, 510
1931	168, 109, 617	( <sup>3</sup> )	7, 398, 867	4. 4	152, 606, 700	37, 414, 521	50, 000, 627
1932	146, 950, 913	( <sup>3</sup> )	6, 154, 449	4. 2	136, 380, 865	44, 541, 336	35, 002, 096
1933	115, 609, 754	( <sup>3</sup> )	5, 020, 625	4. 34	107, 657, 981	35, 800, 271	27, 275, 071
1934	165, 103, 582	1, 355, 657	16, 225, 002	9. 76	139, 681, 129	55, 067, 092	27, 174, 311
1935	180, 645, 920	1, 125, 541	17, 036, 651	9. 45	165, 233, 606	58, 284, 395	38, 746, 679
1936	196, 126, 236	1, 778, 078	24, 572, 512	12. 4	174, 357, 295	64, 955, 485	36, 522, 358
1937	223, 181, 228	13, 304, 547	37, 664, 409	15. 9	181, 034, 322	80, 084, 281	22, 118, 378
1938	201, 033, 858	16, 397, 453	38, 007, 000	17. 4	166, 838, 246	69, 009, 024	25, 598, 717
1939	201, 017, 546	16, 154, 155	34, 042, 757	15. 6	177, 336, 688	83, 561, 077	17, 179, 433
1940	243, 727, 756	17, 293, 791	38, 525, 579	14. 7	225, 160, 792	111, 409, 797	15, 352, 033



1941	298,845,417	20,200,583	41,870,608	13.1	276,766,363	135,834,261	17,676,172
1942	<sup>5</sup> 419,586,596	<sup>5</sup> 97,933,406	51,055,894	9.9	374,760,259	179,217,153	28,628,181
1943	364,698,976	367,651,252	40,313,222	5.5	408,303,779	196,524,631	24,369,788
1944	590,929,045	397,028,657	26,186,608	2.65	973,439,568	471,781,825	52,331,761
1945	650,089,874	451,196,375	71,524,755	6.5	971,446,910	494,008,004	33,087,533
1946	329,386,962	113,030,754	102,252,705	23.1	393,458,500	186,657,673	26,144,437
1947	248,798,639	96,483,242	104,425,567	30.3	537,956,478	147,348,371	36,395,715
1948	332,282,148	87,667,895	88,388,686	21.1	339,651,745	149,394,037	34,887,789

<sup>1</sup> Some of this total amount, perhaps 5,000,000 gallons, was used annually for purposes other than neutral spirits for blending whiskies.

<sup>2</sup> Production was from distilleries in fiscal year 1920, except May and June 1920, due to change of status under title III of the National Prohibition Act, effective October 28, 1919.

<sup>3</sup> No production.

<sup>4</sup> Puerto Rico production included, subsequent to Aug. 1, 1928.

<sup>5</sup> On Jan. 24, 1942, it became legal to make products of distilleries available as alcohol in the war emergency (Public Law 412). Redistillation and transfer became legal on Mar. 27, 1942 (Public Law 508). Figures show net production, after 1942, deducting spirits used in redistillation.

TABLE 2.—*Production of distilled spirits* <sup>1</sup>

Year ended June 30	Total production	Whisky production	Total whisky stocks on hand, June 30 (original gage)
	<i>Proof gallons</i>	<i>Proof gallons</i>	<i>Proof gallons</i>
1933.....	( <sup>2</sup> )	( <sup>2</sup> )	18, 442, 955
1934.....	76, 506, 388	62, 352, 666	57, 717, 662
1935.....	168, 000, 931	149, 112, 923	152, 807, 235
1936.....	252, 089, 847	223, 659, 539	300, 658, 508
1937.....	245, 652, 339	223, 457, 850	445, 285, 663
1938.....	133, 758, 471	102, 895, 872	471, 159, 539
1939.....	129, 172, 021	93, 003, 917	478, 899, 618
1940.....	126, 161, 401	98, 993, 303	480, 937, 609
1941.....	155, 008, 163	121, 851, 983	504, 080, 691
1942.....	157, 981, 798	120, 257, 424	516, 918, 887
1943.....	39, 916, 974	19, 529, 698	424, 824, 966
1944.....	23, 804, 845	None	348, 646, 381
1945.....	73, 105, 032	41, 562, 303	307, 587, 545
1946.....	192, 035, 883	147, 464, 516	374, 072, 056
1947.....	218, 674, 455	167, 994, 805	464, 825, 305
1948.....	156, 459, 458	129, 597, 067	522, 260, 756

Year ended June 30	Grain equivalent of whisky and high-proof spirits produced (56-pound bushels)			
	Corn	Rye	Malt	Wheat or miscellaneous grain <sup>3</sup>
1933.....	( <sup>2</sup> )	( <sup>2</sup> )	( <sup>2</sup> )	( <sup>2</sup> )
1934.....	7, 835, 666	4, 471, 613	2, 127, 374	47, 398 W
1935.....	18, 222, 666	10, 170, 985	4, 557, 621	55, 347 M
1936.....	29, 306, 002	12, 562, 587	6, 221, 831	66, 356 M
1937.....	32, 698, 074	11, 551, 036	6, 394, 013	59, 437 M
1938.....	16, 448, 145	5, 958, 563	3, 210, 582	41, 831 M
1939.....	15, 289, 600	5, 452, 554	2, 719, 270	58, 458 W
1940.....	16, 468, 000	5, 534, 102	3, 028, 870	31, 858 W
1941.....	20, 279, 223	6, 463, 553	3, 811, 465	45, 010 W
1942.....	(About 25.0 million bushels of total grain (estimated)) <sup>4</sup>			
1943.....	(About 4.0 million bushels of total grain (estimated)) <sup>4</sup>			
1944.....	(No production)			
1945.....	(About 8.3 million bushels of total grain (estimated)) <sup>4</sup>			
1946.....	(About 29.5 million bushels of total grain (estimated)) <sup>4 5</sup>			
1947.....	(About 33.5 million bushels of total grain (estimated)) <sup>4 5</sup>			
1948.....	(About 27.0 million bushels of total grain (estimated)) <sup>4 5</sup>			

<sup>1</sup> Includes production of whisky, rum, gin, and brandy only, excluding high-test spirits as reported in table 1, column 3.

<sup>2</sup> End of prohibition era.

<sup>3</sup> W—wheat; M—miscellaneous grains.

<sup>4</sup> For whisky production only. Does not include materials used in industrial alcohol plants.

<sup>5</sup> Total use of *all* grain in distilleries (1946), including high-proof spirits production, was about 55.0 million bushels, 53.1 million bushels in 1947, and 44.5 million bushels in 1948.



The amount of industrial alcohol used annually, previous to the recent war, has fluctuated with general trade activity. While a somewhat increasing trend was shown, there was no opening or development of significant new or enlarged markets over many years. Occasional new or increased consumption in specific lines usually represented less than 10 percent of the normal production. Prices ordinarily remained at low levels, consistent with raw material costs. Whether further lowering of prices would have stimulated significant new markets or increased use is debatable, because ethyl alcohol usually was either the least expensive or the preferred material in the significant application fields. When the recent war began abroad, the industrial demand for alcohol in the United States began to rise, partly for direct export purposes but principally as a result of expanded manufacturing in this country to meet the requirements of foreign warring nations. With the entrance of the United States into the war, the alcohol requirements for munitions, synthetic rubber, and other war uses, plus the needs of allied nations (under lend-lease agreements) raised industrial alcohol requirements to unprecedented figures. Annual production of alcohol reached 580 million wine gallons in the peak period July 1944 to June 1945 (fiscal year 1945). Such production was supplemented by the importation of alcohol from Cuba, Mexico, and Canada, subsequent to 1942, in amounts reaching 33 million wine gallons in 1944.

Since the existing industrial alcohol industry originally did not have sufficient capacity for producing the amounts needed for war demands, it was necessary in 1942 to obtain the assistance of the distilled spirits industry. Therefore, the Government stopped the production of all distilled spirits from grain, and set this industry entirely to industrial alcohol production, insofar as equipment and facilities permitted. Existing equipment was amplified, frequently at Government expense. Many temporary arrangements were made and existing laws and regulations modified to permit the accomplishment of the desired purpose. It is significant that an increase of alcohol production of about 500 percent was achieved by a relatively smaller increase in installed capacity, through the brigading of the industries. This apparent miracle of production was achievable partly because much unused or inactive manufacturing capacity was available in both industries. While production goals were met by this expedient, the situation did not represent an economic ideal, and it could not have been continued successfully under normal production status without further changes. Furthermore, recourse to this expedient caused a shortage of various types of beverage alcohol, with depletions of whisky stocks which have required several years' operation to replace. However, this war expedient brought about definite changes and improved production facilities in the industries.

In the prewar period, as a result of the general situation and of the separate legal status which had been effected, the industrial alcohol and distilled spirits industries had become quite distinct from each other in many ways. Because of market limitations, industrial alcohol production historically has been a highly competitive business, usually operating on a narrow margin of profit, whereas distilled spirits production has been largely a specialty business, with perhaps wider markets and greater usual possibility for profit. Another important factor is represented by the necessity for the distiller to "age" his

product for some years before it is marketable, whereby it becomes impractical to achieve the close correlation between raw material costs and product sales value which is easily possible with industrial alcohol, which can move directly from process to shipment. Differences between the two industries had resulted as to plant equipment and methods, relative amount of labor used, and other plant developments, and especially as to alcohol storage space required and packaging and shipping facilities. With the exception of those industrial alcohol plants which actually were grain distilleries (and operated only occasionally as industrial plants to make high-proof alcohol for beverage blending purposes, usually for their own use), practically all the fermentation type of industrial alcohol plants were designed to use molasses and possessed practically no grain-handling or byproduct-recovery equipment. Conversely, grain only (and no molasses) was used in distilled spirits plants, except for rum manufacture.

The prewar alcohol production capacity (by distillation) of the country was divided rather equally between the industrial alcohol and distilled spirits industries, each industry having an estimated nominal gross potential capacity of about 250 million gallons annually. However, such capacity never had been reached actually nor even exactly determined. For many years previous to the war, the industrial alcohol industry had operated at 40 to 70 percent of normal capacity, as a result of limited markets. The distilled spirits industry, after operating at a comparatively full rate for several years following repeal of the Prohibition Amendment in 1933, also had reduced production after warehouses were filled with a 5 years' supply of distilled spirits.

The impact of the war changed the entire situation. Molasses importation was disrupted, interfering with production from seaboard industrial alcohol plants. Export needs and requirements for munitions disturbed industrial alcohol markets by exhausting stocks. In the emergency, attempts were made to revamp molasses-using plants for the use of grain, particularly as granular wheat flour, but difficulty in obtaining necessary equipment frequently prevented proper installations, and congested railroad traffic affected movement of grain. Most industrial alcohol plants were not advantageously situated for obtaining grain in large amounts continuously. The manufacture of beverage alcohol in distilled spirits plants was stopped and these plants were converted wholly to the production of industrial alcohol. Many of the smaller distilleries, lacking refining equipment adequate for producing alcohol at high concentrations, produced wines of lower concentration instead, and these were shipped to industrial alcohol plants for refining.

These changes represented a virtual merging of the two distinct industries on a war emergency basis. Much trading of equipment and uneconomic cross hauling of raw materials and distillates resulted, together with significant losses of potential byproducts. As an agricultural complication to all this, grain and feed shortages developed because of the increased need for livestock feeding. Thus, it became necessary for the Government to allocate grain-handling and byproduct-recovery equipment to alcohol plants and distilleries which previously had none. The handling of the complex situation in the earlier part of the war period necessarily was influenced by emergency requirements rather than by intent to improve the ultimate welfare

of the two industries. Effort was made later to have alcohol plants return to the types of raw material for which they were best suited, especially after the temporary resumption of molasses importation in 1944 permitted partial return of seaboard industrial alcohol plants to their normal raw material, whereby alcohol production was increased. Sugar-shortages occurring in 1945-47 again affected this situation, however, by the decreased availability of molasses and consequent high molasses costs.

Also, in the war emergency period, a shortage of corn, the grain principally employed by the distilled spirits industry, brought about the substitution of wheat, with which the average distiller had no experience. The reason for this shift was a then-existing surplus of wheat. Use of wheat introduced processing difficulties but these were overcome eventually by research cooperation of Government and industry. Other hitherto unused materials (particularly grain sorghums) also were employed because of fluctuations of supplies of both wheat and corn. During 1946-48 this disturbed situation became perhaps as complicated as during the war. Grain alcohol plants were thrown largely out of operation through raw material shortages or through high grain prices, and surplus potatoes were used in quantity, for the first time, to offset shortages. Food shipments to Europe caused a 60-day shut-down late in 1947 to reduce over-all grain consumption. Subsequent thereto, the use of corn and wheat particularly were limited temporarily by allocation of quotas which were administered by the Department of Agriculture under congressional mandate.

#### INDUSTRY ORGANIZATION

The distilled spirits industry had experienced a period of virtual extinction during the prohibition era. Because of this fact, and the great competition existing in both the industrial alcohol and distilled spirits markets, there had existed little incentive to modernize either industry or to build new plants, for a decade following World War I. The production of synthetic alcohol was begun, and a few new and modern distilleries were built and rushed into production after repeal of the Prohibition Act (1933), but otherwise these industries largely remained in *status quo*.

In 1943, due to war-increased alcohol requirements, a few large industrial alcohol plants were built, largely at Government expense, which in instances were of relatively inadequate design or construction because of limited construction facilities and time. Some breweries also were converted to alcohol production. Almost all the new plants were designed to operate on grain and were located in the midwestern grain-producing areas. Considerable additions to the producing capacities of older grain-, molasses-, and synthetic-alcohol plants also were made. In addition, a few older and smaller plants, ordinarily unable to compete on industrial alcohol operations for economic reasons, operated during the war. Some fruit distilleries also undertook alcohol production.

The geographic location of existing alcohol plants is related to the kind of raw material originally used. Since all older plants were designed to use only one class of raw material, the tendency was to locate them in proximity to such raw material. Thus plants using



molasses are located on waterways (principally at eastern, western, and gulf ports); plants using grain are in or near the grain-producing areas of Indiana, Illinois, Kentucky, Maryland, and Pennsylvania; while synthetic-alcohol plants are located near gas or oil supplies.

As now constituted, the industrial-alcohol industry is an assemblage of various groups or types of plants, each group comprising plants having some similarity as to raw material used or type of product. These groups are comparatively nonrelated. Actual output for the industry is dependent upon the functioning activity within each group. It is not possible to anticipate actual over-all production from the whole industry by a mere summation of the total output capacities of the various groups, since other factors may intervene. However, actual potential output might be estimated with fair accuracy if the

TABLE 3.—*The industrial-alcohol and distilled-spirits industries (1948)*<sup>1</sup>  
INDUSTRIAL-ALCOHOL INDUSTRY

Raw material	Number of plants	Rated (gross) capacity, proof-gallons per day	Estimated capacity for 330-day year, wine gallons of 95-percent alcohol <sup>2</sup>
Fermentation:		<i>Thousands of gallons</i>	<i>Thousands of gallons</i>
Molasses.....	14	1, 203	208, 859
Grain.....	5	296	51, 497
Whey, sulfite liquor, pineapple juice, butyl byproduct.....	8	64	11, 090
Molasses (foreign).....	2	41	7, 087
Distilleries (using grain, duplicated production <sup>3</sup> ).....	13	731	127, 026
Subtotal.....	42	2, 335	405, 559
Synthetic.....	5	761	132, 179
Chemical byproduct.....	2	8	1, 459
Total.....	49	3, 104	539, 197

DISTILLED-SPIRITS INDUSTRY

Grain and molasses <sup>4</sup> .....	146	2, 263	393, 006
Less duplicated production (see footnote 3).....	13	731	127, 026
Net production.....	133	1, 532	265, 090
Gross production (both industries).....		4, 636	805, 177

<sup>1</sup> Based on theoretical rated plant capacity, assuming use of only the best raw material for operation.

<sup>2</sup> Production at these amounts probably not attainable at present, but presumably attainable under comprehensive program. Some plants, however, cannot operate continuously throughout the year. Actual present gross production will vary from 70 to 90 percent of indicated gross future output.

<sup>3</sup> When industrial alcohol is produced at this capacity, it is clear that no distilled spirits production is possible. Actually, plants may be able to produce greater amounts of alcohol as spirits than as industrial alcohol.

<sup>4</sup> About eight of these plants manufacture rum from molasses.

conditions favoring production that govern each group were known. The essential assembly of the industry and nominal output capacity are shown in table 3. However, changes are occurring continually, and plants temporarily may discontinue or resume operations, disappearing from or reappearing on Alcohol Tax Unit listings. (Plants ordinarily retain their Alcohol Tax Unit code number, regardless of status of activity or change of name or ownership.)

The organization of the distilled-spirits industry also is shown in table 3. All these spirits plants (except rum distilleries) use only grain as raw material and produce equivalent grades of distilled spirits by fermentation. Any significant differentiation would have to be based on the relative modernity or obsolescence of the plant, or of its equipment; or on production capacity. However, the plants which normally undertake duplicate operation for certain periods as industrial alcohol plants (i. e., have IAP numbers) are shown separately, since the capacity indicated is largely duplicated in the industrial-alcohol plant capacity. Some of the distilleries which temporarily operate as industrial-alcohol plants cannot produce at full plant capacity on such basis. Production capacities shown in table 3 are subject to 10 to 20 percent variation, as affected by operation difficulties, change of raw materials, and other factors.

Under present conditions, the prewar lines of demarcation among the industries and groups have become less significant. Most molasses industrial plants now are equipped to process grain in some form; conversely grain plants may utilize molasses in the future. Also, many distilleries now are equipped to produce industrial alcohol if desired. (Distilleries which produced industrial alcohol in the war emergency were not required to follow the ordinary procedure of obtaining industrial alcohol-plant operation permits, hence only a small proportion of such plants were actually designated by industrial alcohol permit numbers.)

The arbitrary distribution shown in table 3 is subject to considerable readjustment. Future supplies of molasses may permit the continuing annual production of alcohol at prewar rates ( $\pm 160$  million gallons of alcohol nominally, or peak production perhaps as high as 180 to 250 million gallons), but the processing capacity that actually will be available or thus used and the probable available facilities for raw material shipment are matters of conjecture. The relative price that must be paid for the molasses will affect the situation.

Pure alcohol produced in registered distilleries when temporarily operating as industrial alcohol plants may be utilized more or less directly by affiliated plants for alcohol beverage manufacture (blending), while chemical or synthesis plants may re-use the alcohol product within their own corporate or subsidiary activities. Production from all such plants, while swelling statistical totals, has had minor effect on the actual quantity of industrial alcohol available for the general market, in past years, except to the extent that it has lightened the over-all production load on those producers actually marketing alcohol, by relieving them of that much additional production which otherwise would have had to be made. However, when excess production from petroleum or other sources comes on the regular alcohol markets, in competition therewith, then severe price disturbances may occur.



## CORPORATE FINANCING AND CONTROL

Industrial alcohol plants usually are tied in with other industries more or less effectively. For example, synthetic alcohol is produced largely in plants subsidiary to the petroleum refining industry, or it occurs as a byproduct of certain chemical industries. There are only a few wholly independent operations of significant size. In a statement by Thurman W. Arnold, Assistant Attorney General (38, pp. 810-817), it was noted that, in 1941, 80 percent of prewar normal industrial alcohol production came from five corporate groups as follows:

	Percent
Carbide and Carbon Chemicals Corporation (synthetic)-----	20
Publisher Commercial Alcohol Company-----	18
U. S. Industrial Chemicals, Inc-----	17
E. I. duPont de Nemours and Company-----	13
Commercial Solvents Corporation-----	12
Miscellaneous plants-----	20

In contrast to the industrial alcohol industry, the distilled-spirits industry in past years has consisted of a large number of small, independently owned plants. In the past few years there has been a trend toward consolidation of smaller independent distilleries under four or five large corporate organizations (39, p. 6740). However, acquisition of some of these plants may have been made primarily to obtain the existing warehouse stocks of whisky.

## ALCOHOL IMPORTS

Previous to 1940, the importation of alcohol—other than beverage grades—was insignificant. Tariff charge was 15 cents per gallon. Because of increased needs of alcohol during the war, legislation was enacted, effective October 22, 1942, Revenue Act of 1942, permitting tax-free importation for industrial purposes.

The Bureau of the Census published the following statistics on importation of ethyl alcohol (Code 8231.230):

Calendar year	Total wine gallons	Quantity and origin	
			Countries of origin
1940-----	6	Canada	
1941-----	154	France, Cuba	
1942-----	1, 034, 560	Canada, Mexico, and Cuba	
1943-----	11, 917, 089	Canada, Mexico, and United Kingdom	
1944-----	30, 166, 180	Canada, Mexico, and Cuba	
1945-----	34, 580, 036	Canada, Mexico, Cuba, Brazil, and El Salvador	
1946-----	25, 578, 568	Mexico, Cuba	
1947-----	21, 501, 173	Canada, Cuba	
1948-----	5, 688, 935	Cuba, Argentina, and Brazil	

Beginning with the fiscal year 1948, the Annual Report of the Commissioner of Internal Revenue shows alcohol importation for fiscal years as follows:

Fiscal year	Proof gallons (total withdrawals from customs custody)
1943-----	9, 291, 332
1944-----	32, 538, 679
1945-----	77, 648, 344
1946-----	47, 342, 222
1947-----	31, 953, 552
1948-----	32, 844, 749

## SOURCES OF ALCOHOL

## FERMENTATION PROCESSES

Ethyl alcohol may be derived by fermentation processes from three types of agricultural raw materials: Saccharine materials, in which the carbohydrate—the actual substance from which the alcohol is derived—is present in the form of sugar (as in molasses, sugar beets, sorghum cane, sugarcane, fruit, etc.); starchy materials (cereal grains, root crops, such as potatoes, etc.); and cellulosic materials (wood, agricultural residues, such as cobs, stalks, hulls, etc., and the waste sulfite liquor from paper pulp mills which contains sugars derived from cellulose and hemicellulose hydrolysis). Cellulose, hemicellulose, starch, and sugar all are carbohydrates and have the same general chemical formulation, but their molecular complexity decreases in the order named. Yeast can ferment only the simpler sugars but, to varying extent, all of the more complex carbohydrates can be broken down into fermentable sugars by suitable treatment.

If the raw material originally contains one of the simpler (6-carbon) sugars, such as glucose or fructose, or some 12-carbon sugars, such as maltose, it can be fermented directly to alcohol by a number of varieties of yeast; if it contains one of the more complex carbohydrates (starch, inulin) this must be broken down (hydrolyzed) to water-soluble 6- or 12-carbon sugars before the yeast can do its work. This breaking down can be accomplished by use of enzymes or by mild treatment with acid or other chemical agents. The third type of material, the cellulosic constituents of wood or other vegetation (agricultural residues), normally unfermentable by yeast, may be converted directly to sugars, some of which are fermentable, by hydrolysis with mineral acids. Similar production of fermentable sugars is accomplished to some extent in the production of paper pulp from wood by the sulfite process, the sugars resulting from the chemical treatment remaining in the waste liquor as a dilute solution. After suitable purification of these sugar solutions, derived by either method, fermentation by yeast may be conducted in the same way as with other saccharine materials. However, some of the sugars derived from wood or other vegetation by hydrolysis (pentoses or 5-carbon types) are not fermentable to alcohol by yeast, so that total utilization is not accomplished in such a step. Micro-organisms other than yeast are able to exert fermentative action on carbohydrates, but the resulting products are not necessarily ethyl alcohol.

## SACCHARINE MATERIALS

## MOLASSES

In the United States the bulk of the raw material used for the pre-war production of industrial alcohol by fermentation was molasses. A great part of this molasses was imported from Caribbean areas, principally Cuba. Previous to 1935 this consisted largely of so-called blackstrap, which occurs as an inedible byproduct or normal residue from cane sugar manufacture, about 45 gallons being obtained for every short ton of sugar produced. Since blackstrap molasses is directly related to sugar production, there is a definite maximum of availability. It contains about 50 to 55 percent of ferment-

able sugar consisting mainly of sucrose (cane sugar) and invert (glucose-fructose mixture) in varying proportions (usually about 70 percent sucrose and 30 percent invert). In Cuba, production has fluctuated between 101 million gallons in 1941 to perhaps 332 to 340 million in 1948, averaging about 150 million previous to 1946.

During the prewar period subsequent to 1935 when the sugar quota was in effect, so-called high-test molasses was used extensively for alcohol production also. This molasses is a product of cane sugar or raw cane juice which has been partly hydrolyzed, usually by acid treatment. It usually contains 70 to 78 percent total fermentable sugars, mostly invert. This high-test molasses was produced by Cuban (and a few Dominican, Puerto Rican, and Philippine) sugar interests in an effort to maintain functioning of their organizations under restricted sugar market conditions, since it could be shipped into the United States free of import duty regardless of the sugar quota if for other than human consumption (i. e., inedible use). It represented, therefore, an alternative end product. High-test production rose to a peak of 338.7 million gallons in 1941. None was produced in 1943-47, except that 222.5 million gallons was produced in 1944 in the war emergency.

Statistically, no differentiation is made ordinarily between the various molasses types, and high-test and blackstrap molasses may be blended together for shipment or use. Blackstrap molasses was obtainable at seaboard alcohol plants at 3 to 6 cents a gallon, and high-test molasses sold at equivalent prices based on sugar content; therefore, other carbohydrate raw material ordinarily could not compete for industrial alcohol production. In later prewar years (1935-39) the molasses gallonage consumed annually for industrial alcohol manufacture varied from 160 to 200 million gallons (including both high-test molasses and ordinary blackstrap), averaging 177 million gallons. During the war this rose to a peak of 281 million gallons in 1942. Cuba normally supplied around 75 percent of total blackstrap imports, which were used largely at eastern and Gulf points of entry. Molasses imported from Hawaii and the Philippines was utilized more largely by alcohol plants on the Pacific coast.

There is some uncertainty as to the extent of the future supply of molasses. Past production in sugar-producing countries has approximated (41, pp. 5, 11):

<i>Blackstrap molasses production (year 1937 used as example)</i>		
	<i>Place of origin</i>	<i>Million gallons</i>
Cuba	-----	<sup>1</sup> 150
Dominican Republic	-----	22
Netherlands Indies	-----	70
Peru	-----	20
Haiti	-----	2
British Caribbean	-----	23
Mexico	-----	14
Argentina and Brazil	-----	<sup>2</sup> 66
Total Latin-American production		367



*Blackstrap molasses production (year 1937 used as example)*—Continued

	Place of origin	Million gallons
Philippines	-----	50
United States (continental production)	-----	66
Hawaii and Puerto Rico (shipments only)	-----	<sup>3</sup> 59
Grand total for supply areas	-----	542

<sup>1</sup> In addition, Cuba produced 207.7 million gallons of high-test molasses, equivalent to about 291 million gallons on blackstrap basis. Such production might have been increased, hence the figures in this table do not represent top limits.

<sup>2</sup> About half of this actually was edible grade. (Sirup production not included.)

<sup>3</sup> Production in Puerto Rico estimated at 42 million gallons, in Hawaii at 42 million.

Some of this production is used locally but in general the greater part is shipped to the United States and/or the United Kingdom. During the war, Cuba expanded her alcohol industry considerably, the 27 original plants being increased to 67. Increases to an annual production capacity of around 100 million liters (25 million gallons) were planned, because of war-stimulated demand. During 1944-47, about 83.7 million gallons was purchased by the United States Government. Recently proposed extensions in Cuba of the use of alcohol as motor fuel, and possible yeast and citric-acid production, tend to indicate future increased home consumption of molasses. The pre-war home consumption of molasses was about 23 million gallons, annually, for the production of alcohol, rum, and distilled products (41). Use of molasses in Cuba in 1948 seemingly has been at a rate approximately double the prewar consumption. The output of the 21 distilleries operating was 29.77 million liters (7.86 million gallons). The sugar crop represents Cuba's principal industry and political situations are a factor in the supply status. Programs are subject to change with economic conditions.

Obviously, the future production of high-test molasses will be related to the sugar supply and price situation. When there is an insufficient world supply of crystallized sugar and the price is correspondingly high, it is unlikely that much high-test molasses will be produced. Conversely, with an excess of sugar and low prices, production of high-test molasses may be stimulated regardless of the blackstrap situation.

The recently developed resin ion-exchange process for purifying noncrystallizable or impure sugar solutions permits increased recovery of sugar (sucrose) above the amounts formerly obtainable, with less blackstrap-molasses byproduct. It is not known how far this new process will eventually be incorporated in existing sugar plants. In periods of excess sugar supply, however, economic reasons offer little inducement to effect high-sugar recovery from the cane juice. To date, known ion-exchange installations for cane-sugar manufacture include only one in Cuba and a few in continental United States. About six installations have been made in beet-sugar plants in the United States. The process is being used currently in Hawaii to extract sugar from waste liquors of pineapple processing, and elsewhere to purify corn sirups and citrus wastes. Future extensive application of the process to sugarcane plants might affect the blackstrap-molasses supply, but at present there is little indication of such exten-

sions. The direct tie-in of fermentation alcohol production with sugar mills might be a future possibility.

In addition to use as an alcohol source, molasses finds outlets in the United States for livestock feeding and the manufacture of yeast, vinegar, rum, and citric acid. It has been estimated that around 75 percent of the molasses supply formerly was used for alcohol manufacture and 25 percent for other purposes. Molasses also is used in butanol-acetone manufacture; prewar use varied from 11 to 32 million gallons, but during the war amounted to as much as 60 million gallons. The price of molasses is a determining factor.

Industrial molasses usage (all types), as compiled by the United States Tariff Commission was, in millions of gallons (42):

Use	Year	
	1945 Million gallons	1946 Million gallons
Acetone, butanol.....	43. 0	30. 3
Ethyl alcohol.....	224. 6	103. 4
Flavoring, caramel coloring.....	1. 4	2. 2
Livestock feeds.....	68. 2	82. 3
Spirits, rum.....	10. 6	8. 3
Yeast, citric acid, vinegar.....	47. 3	46. 6
Miscellaneous.....	4. 7	3. 3
Total (general industrial).....	399. 8	276. 4
Desugarizing.....	22. 5	35. 7
Invert production.....		12. 0
Edible molasses.....	4. 2	4. 2
Grand total.....	426. 5	328. 3

#### SUGARCANE

Under certain conditions in the world sugar markets, it may perhaps be economically feasible to produce industrial alcohol by the direct fermentation of sugarcane juice, which contains principally sucrose. About 250 pounds of raw sugar (plus 5.5 gallons of blackstrap molasses) is recovered from a short ton of cane. Computing sugar in juice at 1 cent per pound (basis \$2 per ton for cane), alcohol costs of about 20 cents per gallon are indicated. Sugarcane wax and aconitic acid might be recovered as byproducts, according to studies made by the Bureau of Agricultural and Industrial Chemistry's Agricultural Chemical Research Division, New Orleans, La.

#### SUGAR BEETS

In France the sugar beet has constituted one of the most important commercial sources of alcohol, but in the United States alcohol is not made directly from beets. Alcohol production as an adjunct to beet-sugar manufacture is understood to have been attempted commercially in Utah a number of years ago, but apparently was not economically successful. The juice of the sugar beet contains a variable proportion of fermentable sugar (sucrose), and beets of good quality should yield approximately 23 gallons of 99.5-percent alcohol per ton. Beet molasses, obtained as a byproduct in the manufacture of beet sugar, contains sucrose principally (about 50 percent), and occasionally has been used for the production of alcohol, but production from



this source usually is negligible. Beet molasses is used more largely for the production of yeast and fermentation citric acid. This molasses has relatively high food value and much of it is reused in the beet-sugar plant as an addition to the dried residue pulp sold for livestock feeding or sold to feed mixers. Such uses ordinarily keep beet molasses from becoming a significant potential alcohol raw material. In 1934 it was estimated that about 15 million gallons of domestic beet molasses (discard) reached consuming markets. In that year about 12 million gallons was imported. Increasing use of the ion-exchange process in the beet-sugar industry may reduce future supplies of waste molasses. Since 1943 total production has varied from 50 to 88 million gallons annually, but much of this is used for desugarizing or for edible sirup production, as shown (42) in table 4.

TABLE 4.—*Utilization of beet molasses, in millions of gallons, 1943-46*

Product	1943	1944	1945	1946
Yeast, citric acid, vinegar-----	17. 9	20. 0	28. 1	<sup>1</sup> 31. 2
Mixed feeds and molasses pulp-----	8. 0	6. 0	5. 5	6. 1
Desugarized and edible molasses-----	61. 8	24. 4	22. 6	35. 7
Total-----	87. 7	50. 4	56. 2	73. 0

<sup>1</sup> Approximate distribution—yeast 75 percent, citric acid 14 percent, vinegar 11 percent.

#### CITRUS MOLASSES

Commercial use has been made of "citrus molasses" as a source of alcohol to some extent in recent years. This molasses is made by concentrating the waste waters (press juice) of the citrus canning industry, which are pressed from the pomace prior to drying the pomace for cattle feed. The molasses somewhat resembles cane blackstrap, but has a fruity odor. About 1,800 gallons of waste press liquor, containing on the average about 6.6 percent sugar (range 4.0 to 8.6 percent) usually are obtained for each ton of dry citrus feed produced. Sugar content of the molasses runs about 42 percent, about half of which represents C<sub>6</sub> sugars. Total solids average around 70 percent. Approximately 4 gallons of 95-percent alcohol may result from 100 gallons of liquid press juice. Production of dried citrus feed was at the rate of 67,000 tons annually (in Florida), in 1944, and has increased. Production for 1946-48 is estimated as shown in table 5. Certain byproducts such as hesperidin and naringen and their derivatives might be recovered also. Costs of production of this molasses normally are likely to be relatively higher than for blackstrap and the supply may be relatively limited. The production of feed yeast from citrus wastes has been studied experimentally by the Agricultural Chemical Research Division and the Southern Regional Research Laboratory in a commercial plant at Orlando, Fla., in cooperation with the plant owners.

The production of industrial alcohol from citrus wastes (orange molasses) is reported in California in 1948, use of 606,528 gallons of orange molasses being reported for the fiscal year. A new citrus alcohol plant in Florida is expected to begin operation in 1949.

TABLE 5.—*Citrus byproduct recovery*

Location	Num- ber of plants	Dry feed produc- tion	Number of these plants producing molasses	Molas- ses pro- duction	Season
		<i>Tons</i>		<i>Tons</i>	
Arizona.....	<sup>1</sup> 4	<sup>2</sup> 9, 000	None <sup>3</sup>	None	Average
California.....	9	<sup>4</sup> 22, 000	3	Small	1946
Florida.....	22	154, 181	16	65, 887	1947-48
Texas.....	8	<sup>5</sup> 31, 760	3	4, 675	1947-48

<sup>1</sup> Intermittent operations only.<sup>2</sup> Average production.<sup>3</sup> Sun drying only.<sup>4</sup> Usual range 11,000 to 17,000.<sup>5</sup> Meal and pulp.

## HYDROL

Hydrol, a byproduct sirup resulting from the manufacture of refined corn sugar, might be considered as a minor alcohol source. It contains 70 to 75 percent total solids, which include (dry basis) about 9.5 percent ash, 62.5 percent true dextrose, and some disaccharides. About 28 million pounds was used in 1935 for industrial alcohol. (In the same year, 23 million pounds was used for butanol fermentation also.) However, present methods of producing refined corn sugar from cornstarch utilize hydrochloric acid as the converting agent. This results in a 7 to 8 percent concentration of salt (sodium chloride) in the byproduct sirup, which makes the sirup relatively unfermentable in the normal sugar concentrations employed by alcohol manufacturers. This salt is not easily removed, also certain furfural compounds may be present which inhibit fermentation. In the absence of accurate production data, it may be estimated that perhaps 20 million gallons of hydrol potentially might be available annually as a byproduct from the grain wet-milling industry. Much of it now is used by animal feed producers (around 11 million gallons annually) so that only a relatively small excess might be available for alcohol, normally. Only 186,560 pounds was used for alcohol production (in October 1947) in the fiscal year 1948.

## FRESH OR DRIED FRUITS

Fresh or dried fruit can serve as a source of alcohol. The sugar (fructose) percentages (6 to 12 percent) present in most fresh fruits which are commonly available in quantity are sufficiently high so that the mash concentrations will approach those of usual commercial practice when either the pressed juice or the macerated fruit is fermented directly. Yeast is able to ferment fruit sugar without a hydrolysis step. The chief disadvantages of fruit as raw material for alcohol lie in the relatively high cost and the perishable nature of the material. Apples now are used for the production of beverage spirits (apple brandy); and industrial alcohol is recovered from apple pectin

processing by one plant. Pineapple juice or waste has been used (in Hawaii) since 1931 as a source of industrial alcohol, production ranging from 80,000 to 330,000 wine gallons of alcohol annually. A quantity of 14.5 to 26.5 gallons of pineapple juice is required to make 1 gallon of alcohol, depending upon the stock used.

Dried fruits, such as dates, figs, prunes, and raisins would serve far more successfully than fresh fruits, since storage of the materials would be possible for reasonable periods. Also, sugar concentrations are greatly increased by drying (figs, 45.0 to 50.0 percent; prunes, 55.0 to 60.0 percent; raisins, 62.0 to 68.0 percent; and dates, 60.0 to 70.0 percent). Because of their value as human food the relative cost of these materials ordinarily is too high to permit competition with molasses or cereal grains for alcohol production.

#### CANE SORGHUM

Cane sorghum also may serve as a source of sugar, sugar sirup, or molasses. It contains a mixture of sucrose and glucose. During the season of 1942, under a project sponsored by the United States Department of Agriculture and financed by the Commodity Credit Corporation, 23,252 tons of sorghum cane was employed for alcohol production on an experimental basis. From this cane, 351,401 gallons of sirup of 78 percent solids content was produced by cane sugar factories during inactive periods, thus utilizing idle equipment. This sirup was shipped to New Orleans and processed to alcohol. This trial operation produced alcohol at a critical time, from a hitherto unused raw material, and saved tanker and tank car movements. It also obviated the shipment of equivalent grain and the need for installing grain-handling machinery. Only a short 100-mile haul was involved in transporting the sirup to the distillery.

It is questionable if cane sorghum used in such operation could compete with byproduct sugarcane molasse in normal times. Installation of fermentation equipment at sorgo sugar factories, however, might eliminate a considerable amount of evaporation otherwise necessary to concentrate the material for shipment under the most economical conditions. Since fermentation is conducted at about 12 to 18 percent sugar concentration, in comparison with the high (approximately 78 percent) concentration required for molasses shipment, a considerable simplification might result. Also, the use of evaporators as stills to produce low-grade alcohol which subsequently could be shipped to industrial alcohol plants for further refining, might help to reduce present costs. The development of a sorgo sugar process might provide quantities of a low-grade byproduct, sorgo molasses. The use of the sorgo seed and bagasse as feed might have important application in the South. With suitable change of the processing method, about 5 pounds of aconitic acid and 10 pounds of starch per ton of sorgo also might be obtained as byproducts.

#### WHEY AND SKIM MILK

Whey and skim milk can serve as a source of alcohol, since these materials contain lactose, a fermentable sugar. However, lactose is a more complex sugar (disaccharide or 12-carbon) than simple glucose, and requires special types of yeast. In a process perfected by the



Bureau of Dairy Industry of the United States Department of Agriculture, a species of yeast, *Torula cremoris*, is employed for fermenting whey which occurs as a byproduct of cheese- and casein-manufacturing operations. Fermentation is conducted at 33° to 34° C. on a slightly acidified mash. Yeast is added in amounts equivalent to about 2 percent of the sugar present.

Since 1947 there has been an increasing trend toward utilization of whey for alcohol production. Four small commercial industrial-alcohol plants now operate, the whey sugar being used commercially in one instance for the production of butyl alcohol and the vitamin riboflavin. Plants of these types are situated in dairy-industry centers, such as Kentucky, Michigan, Missouri, and Wisconsin. Lactose is the principal raw material for penicillin production, also.

### STARCHY MATERIALS

The principal starchy materials which may be used in making industrial alcohol are: (a) Cereals (corn, grain sorghum, oats, rye, wheat, barley, and rice); (b) tubers and roots (potatoes, sweetpotatoes, and miscellaneous plant sources such as the Jerusalem artichoke (girasol)). Of these, only corn, grain sorghum, wheat, rye, barley, and potatoes have been used commercially to any great extent in this country. Rice has been used in the Orient. Wheat, barley, rye, and other cereals, as well as potatoes, usually command relatively high prices as foodstuffs, and this restricts their use as raw materials for alcohol except for beverage-alcohol manufacture. In general, alcohol yields under proper processing conditions are in direct relation to starch or sugar content, and the relative value of any raw material in this respect can be computed with fair accuracy. However, each grain requires somewhat different processing conditions and the yields of unfermentable byproducts will vary for each. These factors constitute some of the economic limitations on the selection of any alcohol raw material.

### CORN

Corn, our most abundant cereal, was used to a small extent in the manufacture of industrial alcohol previous to World War II, but such use usually was limited by the relatively high cost of the alcohol at prevailing levels. The alcohol produced from grain generally found special uses, and commanded a market premium. The principal fermentation use of corn was for beverage-alcohol production (see table 2) since it has been the principal source of whisky. The annual use of corn for industrial alcohol during the war rose to a peak of 50 million bushels (1943), about 14 million bushels additional being used for the production of other fermented products, such as beer and butyl alcohol.

### GRAIN SORGHUM

Grain sorghum is nearly comparable to corn as to alcohol yield, methods of handling and processing, and the like. It was not used in significant amounts as a prewar source of alcohol, but since 1944 such use has increased greatly, with more than 42 million bushels, some of it in the form of flour, being used in the peak (fiscal) year 1945. In

addition, limited amounts were used for beer and butanol production in 1945 and 1946. The material is generally very acceptable, and usually has a price advantage, hence the use is continuing.

#### BARLEY

Barley is of interest chiefly from the standpoint of malt production and use. Alcohol production from grain requires malt for the starch-conversion step, unless acid saccharification or the use of mold or bacterial enzymes is employed. Malt is germinated grain, barley being the grain chiefly used. Malting capacity in the United States has permitted production of about 98 million bushels of malt annually. Requirements for malt exceeded production during the war, and an allocation system was enforced. Consumption for malt beverage (beer) production amounted to 71 million bushels annually in 1942-43. An additional 10 million bushels was utilized annually for food products (principally malt sirups) and lend-lease export, while consumption by the alcohol industry reached 30 million bushels per year owing to the greatly increased use of grain. In 1948, 82 million bushels was used for brewing, total use by all the alcohol industries amounting to 92 million bushels in that year. About 37.4 pounds (1.1 standard bushels) of dry, desprouted malt are produced from 1 standard bushel (48 pounds) of original barley. The sprouts, which contain little enzyme but considerable nitrogen, are separated after the malting process and used as an ingredient of stock feeds, and in yeast and vinegar manufacture. Barley itself is seldom used as a direct source of industrial alcohol or for beverage alcohol, except in beer and Scotch-type whisky production.

#### RYE

Rye is used principally for whisky production, where it serves as a basis for a special type of product. Normally its use for industrial alcohol is unusual, although about 11 million bushels was used for emergency alcohol production in the fiscal year 1945. However, although rye is somewhat more difficult to process than corn, the relative grain costs usually permit its substitution for corn as a raw material for beverage alcohol. Rye also is used to some extent for malt production.

#### WHEAT

Because wheat ordinarily does not find industrial uses and is not as acceptable as corn for feeding livestock, stress temporarily was placed on the substitution of wheat for corn as a source of alcohol, during 1943-45, to conserve corn stocks. Wheat protein (gluten) introduces certain technical processing difficulties such as foaming of mashes and fouling of byproduct-recovery equipment, troubles not experienced to the same degree with corn protein. Such difficulties are not sufficient to prevent the fermentative utilization of wheat, but relative plant output capacities may be diminished and processing costs increased, to a small extent, in a plant designed primarily to handle corn. Mixtures of corn and wheat ordinarily are handled without trouble in usual fermentation-plant equipment when the wheat represents less than 50 percent of the mixture, and plant

output capacities then are not adversely affected to significant extent. Use of granular wheat flour actually permits increased unit alcohol production, since the starch content of such flour is higher than that of the original wheat.

Soft wheats, with their lower protein and higher starch content, are more acceptable as distillery materials than high-protein hard wheats, which yield less alcohol because of their usually lower starch content. Much wider ranges of starch and protein percentage occur in wheat because of environment and soil differences where it is produced, than occur in corn. Soft varieties of wheat are grown in areas which usually produce grain of low protein content, and hard varieties in areas which usually produce grain of high-protein content. Selection of wheat for alcohol production must, therefore, be made more critically. About 137 million (60-pound) bushels of whole wheat and 71 million bushels of granular flour (representing approximately 89 million bushels of original wheat) were used for alcohol production from 1942 to 1946. In addition, 102 million pounds of wheat and wheat products was used for beer production from 1940 to 1945. In the peak (fiscal) year 1944, wheat used for all forms of alcohol amounted to about 115 million bushels (partly as flour).

#### GRANULAR FLOUR OR MEAL

Granular flour or meal, prepared from wheat, rye, grain sorghum or other cereals as raw material for alcohol production, has certain advantages for use in molasses-type alcohol plants, in that: (a) This material is of relatively higher starch (or fermentable matter) content than the original grain; (b) the necessity of installing grinding machinery is eliminated; and (c) grain byproducts (bran, etc.) suitable for stock feed are separated by the milling industry and need not be recovered at the alcohol plant, thus avoiding the necessity of installing recovery equipment and of expanding boiler capacity to produce the extra steam needed for processing waste stillage.

#### POTATOES

Potatoes formerly were used extensively for alcohol production in Germany, where they constitute an important agricultural crop. Special types of potatoes of high-starch content (18 to 20 percent) were developed for the purpose, and the technological features of handling the material in small plants were extensively explored. The manufacture and distribution of alcohol in prewar Germany was controlled by the Government. The use of potatoes for alcohol production seemed to be intended to benefit agriculture through advantages derived from crop rotation and stock feeding, and by attaining other benefits of an indirect although important economic character. Actual costs of alcohol production were of secondary importance, since the Government alcohol monopoly absorbed the product, regardless of cost.

The manufacture of alcohol from potatoes in the United States had not attained any commercial importance previous to World War II because molasses and corn represented more abundant, more concentrated, less perishable, and relatively cheaper sources. Idaho operated a small State-owned experimental alcohol plant at Idaho



Falls before the war in an effort to solve State problems relating to potato culls and surpluses.

In 1944, as an emergency measure, the War Food Administration conducted commercial trials of processing surplus potatoes into alcohol by dehydrating the potatoes in inactive beet-sugar plants and shipping the dried, flaked product to alcohol plants for alcohol conversion. This attempt was not an economic success and the actual quantities processed were small.

The machinery available in the beet-sugar plants was not designed for potato handling, so that plant output capacities were reduced, while serious starch losses were incurred. Also, the dried product was variable, ranging from underdried to greatly overdried material. Underdried flakes tended to heat and cake in shipment, causing considerable difficulty in unloading and handling at the alcohol plant. Overdried material was difficult to process and gave lower alcohol yields.

Since the handling equipment available at such alcohol plants as could use this material was designed originally for grain, it was generally inadequate for moving the new material, and much hand labor frequently was required, hence the alcohol plants generally avoided using the material. The dried flakes were approximately equivalent to corn as to alcohol yield and processing requirements, although the quantities of byproduct feed recovered were much less.

Regardless of the possibly more successful outcome of future trials and of the general desirability of finding additional operations suitable for employment of beet-sugar factories in inactive times, it is unlikely that such operation will be economically feasible in normal times. Dehydration costs approximated \$5 per ton of raw potatoes processed, to which freight and potato costs had to be added; consequently, the dehydrated material cost more than corn. About 7 tons of raw potatoes were required to produce 1 ton of dehydrated flakes. This yield might be somewhat improved, 5.5 tons being perhaps optimum. In later experimentation (1946), product costs of \$23 to \$25 per ton were indicated. This process is receiving study by the Eastern Regional Research Laboratory, Wyndmoor, Pa.

Because of shortages of other materials during 1946, potatoes in raw form found relatively extensive use for industrial alcohol manufacture, since other materials actually were available only in small amounts, while large surpluses of potatoes were obtainable from the Government at relatively low prices. Consumption of potatoes by the distilled spirits industry was 280 million pounds during the fiscal year 1946, and 405 million pounds during 1947. At the same time, industrial alcohol plants used 280 million pounds in the fiscal year 1946 and 566 million pounds in 1947. Much of this alcohol subsequently was used in blending whiskies.<sup>9</sup> By the summer of 1947, use of potatoes practically had ceased.

In dealing with the surplus of the 1946 potato crop, the Government

<sup>9</sup> Whisky is defined by law as a product of grain, and other types of beverages are similarly limited by definition. Potato spirit finds no specific beverage outlet except as vodka. Alcohol (so-called neutral spirits) used to "stretch" whiskies heretofore has been produced from grain. In any event, its source must be stated on the bottle label. This has an adverse effect on the use of potato spirit because of consumer prejudice.

sold excess stocks of raw potatoes to the distillers, no dehydration being attempted. A number of alcohol plants installed temporary raw potato handling facilities, but many of these installations subsequently were dismantled. These consisted usually of drag lines, power shovels, or water-flushing systems to move the potatoes from car to a track pit or tank filled with water, which served to catch stones. Usually the potatoes then were moved by open top, spiral flight screw conveyors and spray washed while traveling to hammer mills in which they were reduced to a watery slurry. This slurry was pumped to the regular mash cookers, and the usual manufacturing process was followed from that point. Potato mashes may foam seriously if not properly processed.

Potato surpluses again recurred in even greater amounts in 1948, and further (but probably temporary) use for alcohol production occurred. However, part of the surplus was used to make potato flour for export. Much of this flour was produced in inactive alcohol plants, utilizing the feed drying equipment. Butanol also was produced extensively from surplus potatoes.

#### SWEETPOTATOES

Sweetpotatoes have attracted interest as a source of industrial starch in recent years. Some varieties may contain 30 percent or more of potentially fermentable matter. The culls of this crop might serve as a source of industrial alcohol, the price that could be paid for them probably being about the same as that offered by starch factories. The overflow from the starch-recovery tables might be utilized for alcohol production, although costs of recovering alcohol from dilute solutions might be sufficiently high to make such a process uneconomical. Present growing practices, which tend toward short growing seasons to produce small table-size tubers, do not approach the possibilities inherent in growing sweetpotatoes for industrial uses.

With possible commercial yields of 300 to 400 bushels an acre, sweetpotatoes might represent yields of alcohol, per acre, comparable to those represented by any cereal crop grown in the United States. Sweetpotatoes are difficult to store, however, and thus present a special handling problem since the natural enzymes which are present may cause spoilage. From a technological standpoint, processing sweetpotatoes into alcohol would probably be done in the same manner as with other starchy crops, that is, by crushing and steaming the raw material, saccharifying the starch, and fermenting with yeast. The slop, skins, etc., could be used as cattle food.

A commercial attempt to produce starch from sweetpotatoes, in Florida, began operations in 1947, but is understood to have become inactive because of certain uneconomic conditions. Contemplated erection of a plant to produce alcohol from the tubers, in Louisiana, was announced in 1949. Dehydration of sweetpotatoes can be accomplished in a manner similar to that for white potatoes. Experimentation in this field has been made by one major distiller and by the Southern Regional Research Laboratory. The production of feed yeast from waste waters of sweetpotato processing for starch also has been studied by that Laboratory.

## JERUSALEM ARTICHOKE

The Jerusalem artichoke (girasol, or wild sunflower) tuber has been proposed as a possible source of industrial alcohol in the United States. It was actually used extensively in prewar France. Inulin, the chief carbohydrate constituent, is easily hydrolyzed to levulose (fructose), a fermentable 6-carbon sugar. The production of alcohol from artichokes presents much the same technological features as the use of sugar beets or sweetpotatoes. Commercial crops have been grown in France and used for alcohol production in conjunction with beets, but no significant production has ever been achieved in the United States. Attempts at commercial production of the tubers have been made in several Western States, particularly Nebraska, during the past decade. As with all other farm crops, the use of artichokes for alcohol production would be dependent upon the financial return to farmers and processors. This does not appear to be particularly promising at present. Cultural studies might lead to improvements in carbohydrate content and acre yields.

## CACTI

Sotol, a desert plant of the genus *Dasylirion*, which grows wild in large tonnage and frequently in great concentration in some areas of southern Texas, may have possibilities as an alcohol source material. The plant has a pineapple-shaped head which may weigh 20 to 50 pounds. It ordinarily is obtained from range land simply by cutting and hauling. The heads, stripped of leaves, can be chipped and extracted with hot water or cooked to prepare a mash. Alcohol yields of 15 to 30 gallons per ton are possible. The carbohydrate present is principally inulin, which is easily hydrolyzable to fermentable sugar. A commercial plant attempted operations on sotol about 1944, in Texas, but operation has been discontinued.

Other varieties of cacti also might be utilized, such as lecheguilla, belonging to the *Agave* genus of the family Amaryllidaceae. Several species of *Agave* (century plant or maguey) are used in Mexico for preparing alcoholic beverages, such as mescal and tequila. The carbohydrate in many such cacti is present as a fermentable sugar, rather than as inulin, hence many of these types properly should be listed under saccharine materials.

## MANIOC, ARROWROOT, SAGO, AND TARO

Various other materials of high-starch content such as manioc (also known as mandioca, manihot, cassava, tapioca, raspas, gaplek, bahia, etc.) and arrowroot might be mentioned, although not grown in the United States. Considerable manioc was used in the United States for alcohol production in 1946-47 because of the scarcity of usual materials.

The pith of the sago palm is a tropical source of starch. Dasheen (taro) is another tropical starch plant, which is grown also to a small extent in the South. In general, carbohydrates can be produced more plentifully and at lower cost in the tropics than in the United States. Practically all seeds, roots, etc., contain carbohydrates in varying amounts, hence a long list of possible (but mostly uneconomic) source



materials might be mentioned. Alcohol is understood to have been produced in the tropics from the sap of the nipa palm.

### CELLULOSIC MATERIALS

In addition to the fermentative production of alcohol from farm crops containing sugar or starch, the production from cellulose should be considered. Such alcohol can originate from wood, from cellulosic agricultural residues, and from waste liquor from the manufacture of wood pulp by the sulfite process.

### WOOD AND WOOD WASTES

The utilization of wood for the production of ethyl alcohol entails two essential steps: (a) The hydrolysis of the cellulose of the wood to simple sugars, and (b) the fermentation of these sugars to alcohol by yeast in the usual manner. There are several general processes for carrying out the hydrolysis step. The cellulose may be saccharified by hydrolysis either with acids of low concentration at comparatively high temperatures, or with concentrated acids at comparatively low temperatures.

Considerable experimentation was carried on in this country years ago in attempts to utilize sawdust and mill waste for alcohol production, and ethyl alcohol was produced commercially from sawdust (1915) at plants located at Georgetown, S. C., and Fullerton, La. In this early work, a dilute sulfuric acid process was used. Yields equivalent to 20 to 25 gallons of alcohol per ton of dry coniferous wood waste (15 to 20 percent bark) were obtained. However, yields were considerably less with the wood of nonconiferous or broadleaved trees.<sup>10</sup> Industrial production of alcohol in the United States by this method was not profitable because of competition from cheap molasses, and after World War I the plants were dismantled.

Alcohol production from wood wastes was intensified abroad, however, before the recent war (19), since wood waste was more economically available than grain or molasses. Two processes were developed in Germany, in which high yields of alcohol were claimed. In one, the Scholler process (1926), dilute sulfuric acid of 0.2 to 1.0 percent concentration is circulated through layers of sawdust or wood chips, under pressure, at a temperature of 121° to 180° C. The sugar produced in the hydrolysis is easily destroyed by the acid, hence it must be quickly and continuously removed. A wort containing about 3 percent of sugar is obtained. The free acid is neutralized with lime, after which the wort is fermented in the usual manner. Urea, monosodium phosphate, etc., are usually added to improve yeast action. Yields of about 50 gallons of alcohol are obtained per ton of dry, bark-free coniferous wood. Lignin from the wood is recovered from the converters. Considerable quantities of dry yeast, suitable for livestock feeding, can be grown on the (xylose) sugars unfermentable by the yeast.

<sup>10</sup> Hardwoods contain relatively higher percentages of pentosans and correspondingly less cellulose than coniferous woods. Since both pentosans and cellulose are hydrolyzed in the process, less 6-carbon sugar and more 5-carbon sugar is produced from hardwoods, hence less alcohol and more xylose result.

In the other, known as the Bergius process, concentrated hydrochloric acid is used as the saccharifying agent. The use of concentrated acid requires special acid-resistant equipment and necessitates recovery of the acid, both of which complicate the process and increase the capital outlay. Also, the sugar produced must be rehydrolyzed before it can be fermented. For these reasons the Bergius process has not been as commercially attractive as the Scholler, especially since the latter process permits variations in degree of hydrolysis. About 21 foreign plants are understood to have operated on wood wastes by 1941. Three Scholler and two Bergius plants were located in Germany.

A proposed modification of the Scholler process attempts only partial conversion of the cellulose, which reduces alcohol yields (18 to 20 gallons) but leaves utilizable residues. However, this has not been developed commercially. Another recent process, also a modification of the Scholler process, has been developed at the Forest Products Laboratory, Madison, Wis., and is known as the Madison wood-sugar process. It takes advantage of the kinetics of cellulose saccharification to reduce processing time notably, in comparison with the Scholler method. By this process, in 3 to 5 hours, a bark-free wood can be converted into solutions containing 5 to 6 percent reducing sugars which, on fermentation, produce alcohol in yields of 50 to 65 gallons per ton of dry, bark-free coniferous wood.<sup>11</sup> A residue of about 30 percent of the original wood remains (lignin) which may have value as a plastics extender, as a soil mulch, or for other uses. Yeast may be recovered for recycling.

The relative value of conversion processes for wood as a source of alcohol will depend on the cost of the raw material and processing, and on the utilization of the lignin and other residues so as to obtain offsetting credits. Alcohol costs of 20 to 30 cents per gallon have been estimated. Vast amounts of alcohol might be produced from annual wood wastes or from cellulose in general if an economic process were perfected. Some of the other sugars (principally pentoses) formed in the hydrolysis, but not decomposed into alcohol by the yeast, may be utilized for the production of furfural or other chemicals, food yeast, or stock-feed ingredients.

Wood wastes exist in large quantities. In ordinary lumbering operations only about one-third of the tree is recovered as finished lumber. Economic utilization of the remainder for alcohol production would depend on location or concentration of these wastes at selected points in amounts sufficient to permit economic plant operation, and on the type of process used. These wastes sometimes are concentrated at one spot, particularly as sawdust. A considerable amount of such waste is now used as fuel.

It can be estimated that a plant of economic size (12,000 gallons of alcohol per day) would have to utilize 220 to 250 tons of dry, mill-run wood waste per day to produce 4.1 million gallons of alcohol

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<sup>11</sup> If more dilute sugar solutions can be handled economically, yields as high as 75 gallons of alcohol might be obtainable. Theoretical yield is about 95 gallons.

per year.<sup>12</sup> The number of operating mills of a size sufficient to permit adjunct hydrolysis operations is somewhat limited. The actual availability of waste—that is, the net amount available—introduces limitations.

Steps already have been taken for the commercial development of alcohol production from wood waste in the United States. One commercial plant was erected at Springfield, Oreg., by Defense Plants Corporation. It was intended for use in the war emergency, but was not completed until after the end of hostilities. The plant was operated on a trial basis by private interests for a short time in the summer of 1947. The dilute-acid process used is based largely on improvements made on the original Scholler process by the Forest Products Laboratory of the United States Department of Agriculture, Madison, Wis. This agency may continue to study the plant operations for further improvements if operations are resumed.

Recently that Laboratory has suggested, in lieu of alcohol production, that feed-yeast production from the sugar solutions might be economically feasible. Also, the sugar solutions can be evaporated to molasses concentration and utilized as a substitute for blackstrap or beet molasses in mixed stock feeds. Yields of total sugar equivalent to 45 to 50 percent of the original wood substance are reported. The ratio of 6-carbon to 5-carbon sugars in this molasses may be relatively high, and the material might be exchangeable with cane and beet molasses, for stock feeding, according to results from pilot-plant operations at Springfield. Furfural and methanol are flashed from the hydrolysis liquor and recovered. Costs of the molasses are estimated at around \$20 per ton. Yeast production costs from the molasses may approximate 5 cents per pound, based on preliminary estimates.

The production of chemicals from wood by hydrogenation also has been proposed.

#### AGRICULTURAL RESIDUES

Cellulosic agricultural residues similarly could be used in lieu of wood in these same processes, since such residues also consist essentially of cellulose, pentosans, and lignin. However, although the total carbohydrate content of agricultural residues is about the same as that of wood (65 to 70 percent), agricultural residues contain relatively less cellulose but considerably more pentosans. The same amount of alcohol-yielding sugar (dextrose) could not be produced from a ton of agricultural residues as can be made from a ton of wood. The relatively low cellulose and high pentosan content of agricultural residues may not be a liability, however, since several industrially valuable products can be made alternatively from these pentosans; for example, butyl alcohol, acetone, furfural, xylose, xylitol, and fodder yeast. Such industrial products producible from the pentosans not only might help defray the cost of alcohol production but also might make the

<sup>12</sup> According to estimates of the War Production Board, the cost of a plant producing alcohol from nonfood raw materials is \$500,000 or less per million gallons of annual production. That is one and six-tenths to twice the prewar cost of the ordinary grain fermentation plant. The cost of the plant at Springfield, Oreg., is estimated to be around \$3,100,000 for a predicted yearly capacity of about 4 million gallons of 95-percent alcohol.



sale of lignin a less important factor in the economics of the whole saccharification operation.

The Synthetic Liquid Fuels Project in Peoria, Ill., of the Bureau of Agricultural and Industrial Chemistry, is investigating, on a semi-works scale, the cost of a process for the conversion of agricultural residues to xylose and dextrose for ultimate conversion to products utilizable as motor fuels. The semiworks plant has a theoretical capacity of 3.3 tons of agricultural residues per 8-hour day, producing approximately 1 ton of glucose (at 10-percent concentration), 1,600 pounds of xylose (at 15-percent concentration), 200 pounds of furfural, and a residue of 1,000 pounds of lignin.

In the two-stage process under investigation it should be possible to hydrolyze, with dilute sulfuric acid, about 90 percent of the pentosans in the first stage, with a simultaneous hydrolysis of only a negligible amount of the cellulose. The cellulose may then be converted to dextrose by a second hydrolysis with concentrated sulfuric acid. By these two steps the xylose and the dextrose sugars are produced separately and thus each can be converted to end products under conditions optimum for the respective sugar (for example, butanol/acetone from the xylose by fermentation with *Clostridium acetobutylicum* or related organisms, and ethyl alcohol from the dextrose by yeast fermentation).

For every pound of grain grown, about 1 to 1½ pounds of straw, corncobs, corn stover, or other residues also are produced. Huge quantities of residue material potentially might be available. This material is now largely unavailable for industrial use because normally it is scattered throughout the farming areas, making the costs of collection an impeding factor to greater utilization. However, in some instances certain farm residues are collected as byproducts at central points in ordinary food or textile processing operations (corncobs, rice hulls, sugarcane bagasse, oat hulls, flax shives, peanut hulls, etc.). These collected residues frequently are used as fuel although in a few cases, such as in the use of oat hulls and corncobs for furfural manufacture and bagasse for insulating board, the concentrations are sufficiently large to support existing and important industrial operations.

#### SULFITE LIQUOR

Alcohol may be obtained indirectly from wood by fermenting the waste liquors from the sulfite pulping process used in producing paper pulp. The pulping process aims at separating lignin and some hemicellulose from the usable cellulose fiber. Derivatives of these separated compounds, together with fermentable sugar from the less resistant fractions of cellulose, appear in the 2,000 to 2,300 gallons of waste liquor resulting from production of 1 ton of pulp. This liquor contains 2 to 4 percent sugar, of which about 65 percent is fermentable to alcohol by yeast. Before such liquor can be fermented, however, the sulfur dioxide as well as the acetic and formic acids present in the solution must be neutralized, usually with lime. The sulfur dioxide gas largely can be removed by aeration or by steam stripping before neutralization. About 60 pounds of steam are required for each 100 gallons of liquor,<sup>13</sup> and about 25 percent of the original sulfur dioxide can be recovered for reuse in the paper process. By such treatment,

<sup>13</sup> Private communications, M. M. Rosten, E. E. Harris.

less lime is needed for neutralization. Special types of yeast may be required, and the addition of urea or other source of nitrogen may be necessary to sustain yeast action. Fermentation periods run about 10 hours. Alcohol yields are about 1 percent of the volume of liquid fermented; hence relatively large distillation and steam production capacities are required.

Alcohol recovery from this source has been commercially successful abroad, particularly in Sweden and Germany, but a commercial attempt in the United States some years ago was abandoned in 1939. A new commercial plant began operations at Thorold, Ontario, Canada, in 1943 and has been operating with technical success. Production capacity approximates nearly 1 million gallons of alcohol per year (3,000 gallons per day) from pulping operations of about 120 tons per day. A portion of the original sulfite liquor is used for separate feed or bakers'-yeast production. Yields of 18 to 20 gallons per ton of wood pulp produced are reported.

The distinctive features of the process are the continuous reuse of the yeast, short fermentation periods, low plant-labor requirements, and simplicity of operations.<sup>14</sup> Potential yields of 25 gallons of alcohol per ton of wood pulp produced are claimed. Previous disadvantages of the process were the extreme dilution of the solutions and consequent high-steam requirements, the expense of prepurification of the liquors, and the waste of nonfermentable (5-carbon) sugars. These sugars can serve as a source of feed yeast if treated in a supplementary process.

A plant for producing alcohol from waste sulfite pulping liquor was built in 1944 by Defense Plants Corporation in Bellingham, Wash., for war emergency purposes. First operation was achieved in 1945. This plant, which is reported to have a production capacity of about 2½ to 3¼ million gallons of alcohol per year, was purchased from the Government by the lessee operators in 1947. Methanol and sulfur dioxide are removed from the product by a special flashing operation. The ethyl alcohol from both this and the Thorold plant apparently is competing commercially with that from other source materials, at current alcohol prices.<sup>15</sup>

If the process proves to be economic under future market conditions, a large potential source of relatively low cost alcohol might be a possibility. There are perhaps 35 pulp mills of sufficient size (100-tons-per-day pulp output, minimum) to carry on alcohol recovery. A potential 40 million gallons of alcohol is conceivable from this source alone. It is claimed that future costs, based on large operations, may be as low as 12 cents per gallon (10), although 16 to 20 cents would probably be a more dependable estimate.<sup>16</sup>

Ordinarily, the sulfite liquor is furnished practically free to alcohol processing subsidiaries; any substantial charge for this would have a corresponding effect on alcohol cost. Because of possible contami-

<sup>14</sup> See footnote 13.

<sup>15</sup> In 1947, the Commercial Alcohols Company, Ltd., of Montreal began construction of a \$2,750,000 sulfite alcohol plant at Gatineau, Canada, to produce 2 to 3 million (U. S.) gallons annually. Operations began in January 1949. The plant is understood to be of special design.

<sup>16</sup> This process has been commercially employed extensively in Sweden and Norway. Costs of alcohol, according to private sources, were about 18 cents per gallon, in tanks, at works, without profit.

nation with methanol (wood alcohol) the use of the alcohol thus produced might be limited in certain fields. However, it is possible with adequate distillation equipment to remove this methanol completely. Actually, a considerable portion of the methanol is eliminated in the preliminary stage of sulfur dioxide removal. The relatively large quantities of processing steam required constitute an economic limitation which, if solved, might improve the competitive status of sulfite liquor. About 100 gallons of liquor must be processed to obtain 1 gallon of alcohol.

## FERMENTATION PROCEDURES

Most fermentation-type alcohol plants follow a generally similar process, although in each plant there are differences in the raw material used, the type of equipment, the yeast strain, the processing temperature ranges and other factors, the concentrations employed, and the recovery of byproducts. Fermentation is conducted in large tanks or vats that now usually are constructed of steel, although wooden-stave tanks formerly were used. Steel fermenters usually are of closed-top construction to permit recovery of byproduct carbon dioxide gas and to afford better means of steam sterilization. With wood tanks no gas could be recovered unless special closed tops were provided, sterilization was difficult, and leakage often occurred. Modern fermenters may be equipped with cooling coils or circulating pumps to afford control of fermentation temperatures.

In fermenting molasses, the raw material is diluted to a concentration of 16 to 20 percent sugar and active yeast is added after the acidity of the solution is adjusted to the optimum (about 5.0 pH) for best fermentation. Yeast is used in amounts approximating 3 percent of the total mash volume. Presterilization of the molasses solution usually is not practiced. Initial inoculation with yeast usually is made at mash temperatures of about 78° F., and effort is made to avoid too rapid fermentation, foaming, etc., by holding the temperature below 90° F. Fermentation usually is complete in 48 to 55 hours, depending upon temperatures, concentrations, and other factors, after which the fermented beer is passed to dealcoholizing and refining stills. In certain instances when some recovery of residues may be indicated, other subsequent processing steps such as screening, evaporating, and drying are carried out. Fruit and other sugar-containing materials would be handled similarly, with macerating and steam sterilizing steps preceding the fermentation.

When grain of any material containing starch is used, handling, cleaning, weighing, milling, and cooking must precede the actual fermentation. These steps constitute an essential and relatively expensive part of the process. After the cooking, which historically is a batch process, usually accomplished in horizontal steel pressure cookers equipped with steam jets and stirring mechanisms,<sup>17</sup> the "mash" must be converted, i. e., the cooked starch must be changed

<sup>17</sup> The German Henze process substitutes steam explosion for the usual steps of milling and cooking with agitation. About a dozen United States plants are equipped to use this method, particularly for potato processing. The method might be applied to corn, also, and is stated to represent a cost saving compared to usual milling procedures; but feed recovery by screening is adversely affected.



to sugar. This change is effected by malt, which contains the necessary enzymes. Cooking generally is done on dilutions equivalent to 20 to 25 gallons of final slurry for each 56-pound bushel of grain used. Temperatures ranging from 250° to 350° F. are employed, depending on the type of material and equipment. A batch cooking cycle ordinarily extends about 2 hours from filling to dumping. Before the addition of malt the temperature of the cooked mash must be lowered below 145° F., so as not to destroy the malt enzyme. The amount of malt added usually is about 8 percent (dry weight) of the original grain contained in the batch, a cold water suspension of ground malt being used. Quantities of 10 to 12 percent may be employed, particularly for whisky production. A portion of the malt usually is added previous to the cooking to effect some conversion of starch and reduce the viscosity of the grain slurry.<sup>18</sup> Recently, because malt is relatively expensive, the use of enzymes produced by molds or bacteria in lieu of malt has been tried commercially. Substitution of mineral acid hydrolysis for malting has been advocated for industrial alcohol production, but it is impractical for distilled spirits. Much experimentation is being done, but to our knowledge no plant is using an acid process commercially at this time.

The cooking process has been simplified recently by substituting continuous operation for batch processing. A mixture of ground grain suspended in water is pumped in a continuous stream through a steam jet, where it meets high-pressure steam at about 350° F. After passing through the jet, the heated slurry is held at this temperature and pressure for 4 to 10 minutes by use of long pipes or catch tanks. The slurry then enters a flash chamber where the pressure is relieved and excess steam is flashed off for reuse. The partly cooled slurry then passes through a second flash chamber where the temperature is reduced to around 160° F. by employment of vacuum (usually a barometric condenser). At the exit from this chamber a cold malt slurry is injected continuously, so that a mash temperature of 145° is reached immediately. The mixture then passes through cooling coils to the fermenters, where much of the starch hydrolysis subsequently occurs. This process requires much less equipment and labor than the batch process, and it has been installed in many plants.

After cooking, malting, and cooling, the mash usually is at a concentration of 30 to 45 gallons per bushel of grain and at a temperature of 78° F. as received in the fermenters. The fermentation procedure is substantially the same as that for molasses, until after distillation. Yeast volumes used represent about 3 percent of the total mash. After distillation, recovery must be made of the unfermented residues in the waste (stillage) from the dealcoholizing still. This entails an extensive recovery plant, usually known as a dryhouse, which is relatively expensive as to both plant and operation. Grain processing requires perhaps three to five times as much steam as molasses processing. This necessitates larger boiler plants, more equipment, and much more extensive personnel than a molasses plant. The higher costs are somewhat offset by the larger amount of byproducts and the higher return value usually obtainable from them.

Processing of potatoes or other starchy root materials represents

<sup>18</sup> So-called premalting or preliquefaction.

an operation intermediate between those for grain and for molasses. Simple maceration may replace grain milling, dryhouse equipment requirements are less than for grain, and steam requirements also are reduced. Malt requirements are in proportion to starch content. Where inulin rather than starch is present, conversion can be accomplished without the use of malt.

The fermentation step for wood sugars is analogous to that for molasses, except that neutralization of the raw solutions is necessary. The equipment for the hydrolysis of wood represents a greater percentage of the total capital investment. Equipment for recovery of byproducts, as well as steam requirements, differs greatly from that required for grain operations.

The production of yeast in a distillery is accomplished in stages of increasing size; usually the start is from a small culture and the succeeding steps, each producing a larger quantity (at least a 10:1 ratio), are timed to coincide with the operation cycle of the fermenters. The yeast is grown on a mash comparable with the general type of material fermented in the alcohol plant, and is maintained at an acidity of approximately 4.5 pH to retard growth of deleterious bacteria. The yeast is added to the fermenter mash when at the peak of budding activity. Some distilleries use lactic acid instead of sulfuric acid to adjust the acidity of the yeast. In such cases, a 24-hour lactic acid fermentation precedes the yeast production operation, the lactic organisms being killed by heat previous to yeast inoculation.

Grain plants usually are confronted with the necessity of storing raw material sufficient for operations for extended periods. Moisture in the grain, if excessive (over 15.5 percent), may bring problems of grain heating, or damage by micro-organisms. Milling becomes difficult at a moisture content exceeding 17.5 percent. Drying of grain by heat may affect the fermentability, if too high temperatures are employed. A range of 130° to 170° F. may be allowable, but must not be exceeded. However, mold or heat-damaged grain apparently can be fermented without much loss of alcohol yield.

## SYNTHETIC ALCOHOL

When evaluating agricultural materials which require fermentation as sources of industrial alcohol, attention should be paid to competing sources which may represent lower cost production.

Alcohol can be produced by synthesis from certain gases, particularly ethylene. Ethylene is a normal constituent of both natural and coke oven gases, and of the waste gases from petroleum refining in producing gasoline, although in many instances only small amounts (3 to 6 percent) are present. It may also be produced by pyrolysis of ethane or propane, which also are present in such waste gases (21). It occurs in byproduct gases originating from synthetic gasoline production in the Fischer-Tropsch and Synthol processes. Scrubbing of such gases (of suitable and relatively high ethylene content and semipurified by removal of other interfering hydrocarbons) with concentrated sulfuric acid under pressure removes the ethylene as ethyl hydrogen sulfate, which in turn is easily hydrolyzed by water to ethyl alcohol. Yields of alcohol obtained are about 90 percent of theoretical (5). Some ether (5 percent of total yield) is formed as a byproduct. The

sulfuric acid may be regenerated for reuse, or recovered as ammonium sulfate. The recovery or utilization of the byproduct sulfuric acid has constituted a process disadvantage, but recent developments in vapor-phase hydrolysis indicate that the problem can be simplified. The direct hydration of ethylene by water vapor, without use of acid, has recently become commercially practicable.

Comparatively large amounts of ethylene contained in waste refinery gases and natural gas now are not utilized chemically. They represent a source of additional large quantities of alcohol or secondary chemical products thereof, if and when it is possible to recover such ethylene economically. One limitation on production of alcohol or chemicals from gas is the capital investment required, which is much higher than the similar requirement for fermentation alcohol plants. This is largely owing to the high expense of the corrosion-resistant equipment which must be used in the sulfuric acid process (7). However, the relatively low raw material costs apparently can offset the initial disadvantage. About 4.5 pounds of ethylene (4.05 theoretically) are required to make a gallon of alcohol. Over-all production costs of the alcohol have been variously given as 12 to 18 cents per gallon, based on prewar ethylene values. Processing costs at present are stated to be less than 10 cents per gallon (5) including credits for reconverted acid. Amortization costs are relatively high. Future production necessarily will be related to the availability and competitive cost of ethylene. As a result of the synthetic rubber program (styrene production) demands, ethylene costs during the war rose as high as 4.5 to 6.0 cents per pound, increasing alcohol production costs significantly. Recently, natural gas costs have gone to high levels. Ethylene production in 1946 was estimated at 295 million pounds. Plant capacity (1948) for ethylene production from natural gas is stated to be 3.4 million pounds daily (13), but actual production approximated 700,000 pounds.

Synthesis of alcohol from other gases is possible. Acetylene gas is available from calcium carbide or by pyrolysis of propane or natural gas (13), and commercial production of ethyl compounds or of acetic acid is possible by oxidizing the acetylene to acetaldehyde, with subsequent reduction to alcohol or further oxidation to acetic acid. This process now is used in Canada and at Niagara Falls, N. Y., to produce acetic acid (which is oxidized ethyl alcohol), but not to produce alcohol.<sup>19</sup>

It also is possible to make certain ethyl products, such as ethyl acetate, by direct catalysis from ethylene without preliminary recovery of alcohol in concentrated, purified form. Acetic acid and ethyl ester production now constitute a large portion of the market for alcohol, and their direct production from ethylene or acetylene is increasing. The complexity of the synthetic production of chemicals is shown by the fact that one company produces formaldehyde, methanol, acetone, acetaldehyde, acetic acid, iso- and normal-propyl and butyl alcohols, etc., in one plant, using only butane, propane, and natural gas (as a hydrogen source) as raw materials. This operation essentially is one continuous process, the various end

<sup>19</sup> It is understood that this process was used commercially for alcohol production in Europe (11).



products being derived as fractions, or developed from respective fractions, of the product stream.

Alcohol also is formed or recovered in certain chemical operations, such as methanol synthesis and ethyl-cellulose manufacture. However, present production from these sources is relatively small.

A hitherto untapped source of alcohol may lie in high-pressure synthesis from carbon dioxide. Methanol is now made extensively from carbon monoxide plus hydrogen, by catalytic synthesis under high-pressure conditions. Carbon dioxide, which is available in large amounts, can be reduced to carbon monoxide. Variations of flow constants or substitution of other gases for carbon monoxide can yield alcohols (or derivatives) higher in the series than methanol. (The hydrogen required for such synthesis can be produced by the reaction of hydrocarbons with steam, but in part it is also a natural constituent of the raw gases used as raw material.) Certain butyl alcohols are now produced commercially by such reactions.

Although tried abroad, particularly in Germany and France, and although a number of patents are extant, there has been little inducement to make ethanol by such methods because of the competition from other sources. However, the possibility exists. Any visualization of the future production of alcohol by fermentation processes for industrial or fuel purposes from relatively expensive farm products must be limited by the prospect of cheap alcohol from chemical sources. In the Fischer-Tropsch process, for example, wherein carbon monoxide is combined with hydrogen to make synthetic gasoline, usually a mixture of alcohols also occurs as a byproduct. A somewhat related method of synthesis from carbon monoxide, ethylene, and hydrogen, originating in Germany and known as the OXO process, is directed particularly to the production of higher carbon aldehydes and alcohols. It is understood that several commercial OXO plants in this country are contemplated, based on petroleum as raw material.

The synthetic-ethanol industry has made a tremendous advance in the United States, as shown in table 6. Production was started originally by the Carbide and Chemicals Company at Charleston, W. Va., about 1929, to synthesize ethyl alcohol from ethylene obtained from natural gas. A second plant was erected about 1933 at Whiting, Ind., for utilizing waste gas from an adjoining petroleum refinery. Later, a plant was built at Texas City, Texas (1940), presumably to be operated in conjunction with a petroleum refining operation. A plant also was built in 1943 at Baton Rouge, La., by a southern oil company, to use ethylene in gas derived from nearby petroleum refining plants. During the war the capacity of existing plants was increased. Production from all plants reached 74 million gallons in 1948 (fiscal year), and 1 new plant (of reputed 18 million gallons annual capacity) subsequently began operation about September 1948 in Texas, using ethylene vapor-phase hydration instead of sulfuric acid hydrolysis. Several other plants are being constructed in Texas, for the production of ethylene or chemical derivatives (particularly acetaldehyde) from natural gas, or from waste petroleum gases. Heretofore, synthetic ethyl alcohol usually has been sold (to subsidiaries) on contract for industrial purposes, so that little of it reached the free market. During the war most of it was used for producing butadiene, the raw material for synthetic rubber, which

necessitated some of the plant expansion that has occurred. This situation may change as excess production becomes available.

TABLE 6.—*Trends in industrial alcohol production, by fiscal years, from various raw material sources*<sup>1</sup>

Source	1934	1935	1936	1937	1938	1939	1940	1941
	<i>Per-</i> <i>cent</i>	<i>Per-</i> <i>cent</i>	<i>Per-</i> <i>cent</i>	<i>Per-</i> <i>cent</i>	<i>Per-</i> <i>cent</i>	<i>Per-</i> <i>cent</i>	<i>Per-</i> <i>cent</i>	<i>Per-</i> <i>cent</i>
Molasses.....	83.4	85.5	76.2	75.7	73.1	67.6	68.56	70.41
Grain.....	6.3	2.7	7.0	8.4	9.1	7.7	5.73	5.87
Synthetic.....	7.3	9.7	16.0	15.2	17.6	23.9	25.12	23.39
Other.....	3.0	2.1	.8	.7	.2	.8	.59	.33
Unfinished spirits.....								
Potatoes <sup>4</sup> .....								
Sulfite liquor.....								

Source	1942 <sup>2</sup>	1943 <sup>2</sup>	1944 <sup>2</sup>	1945 <sup>2</sup>	1946 <sup>2</sup>	1947 <sup>2</sup>	1948
	<i>Per-</i> <i>cent</i>	<i>Per-</i> <i>cent</i>	<i>Per-</i> <i>cent</i>	<i>Per-</i> <i>cent</i>	<i>Per-</i> <i>cent</i>	<i>Per-</i> <i>cent</i>	<i>Per-</i> <i>cent</i>
Molasses.....	68.13	35.55	32.60	27.83	24.64	18.12	38.75
Grain.....	9.08	24.09	32.40	41.22	26.69	13.30	9.44
Synthetic.....	21.33	21.60	17.87	16.34	36.07	44.60	38.18
Other.....	.26	.57 <sup>3</sup>	10.02	9.54	1.03	1.64	2.50
Unfinished spirits.....	1.20	18.19	7.11	4.82	6.70	16.58	9.40
Potatoes <sup>4</sup> .....					1.07	4.30	1.32
Sulfite liquor.....				.25	.80	1.46	1.41

<sup>1</sup> The general production trend is not accurately reflected by the percentages shown for 1942-45, being disguised by (a) current shortages of molasses, (b) increased use of grain as raw material, (c) conversion of the entire beverage alcohol industry temporarily to industrial alcohol production for war purposes, and (d) large increases of total production occasioned by the war, which exceed the relative increases in synthetic-alcohol production.

<sup>2</sup> Based on production in industrial alcohol plants only, but including unfinished spirits originally produced in distilleries (largely from grain) and transferred to industrial alcohol plants for refining.

<sup>3</sup> Mainly from grain mixtures.

<sup>4</sup> These percentages actually should be slightly higher (0.1-0.2) because of potatoes used in mixtures, shown herein as other.

The proportionate production of synthetic industrial alcohol is shown in table 6. Since future production by synthesis may equal the total annual prewar industrial alcohol consumption, the future economic status of fermentation production methods may be significantly endangered, if plants for synthetic production are operated at full capacity. Early in 1949 it appeared that the actual production capacity of all the synthetic plants may approximate 111 million gallons per year, with further increases in sight.

### ANHYDROUS ALCOHOL

Within the past 25 years alcohol has been produced commercially to some extent in relatively anhydrous form for special uses. This

alcohol is usually made in this country from 190-proof (95 percent) alcohol, although foreign processes before the war included continuous processing methods in which the anhydrous alcohol was produced directly from the original fermented mash. There are perhaps seven commercial installations in this country. The method principally used is known as azeotropic distillation. Ordinarily, alcohol and water form a constant boiling mixture (at 95.57 percent alcohol by volume) which is not easily separated by distillation, since it boils at a temperature slightly below the boiling temperature of pure ethanol. Hence most alcohol is sold commercially at the 95-percent average concentration easily achieved in ordinary distillation procedures.

However, if certain organic liquids are added to and distilled with the 95-percent alcohol, it is possible to separate and continuously remove a mixture of alcohol and the organic agent which also will contain practically all the water originally present in the alcohol. Benzol (coal-tar benzene) ordinarily is used in the United States as the azeotropic agent (four plants), while in Germany trichlorethylene (Drawinol process) was largely used before the war. One American plant uses isopropyl ether, and one Canadian plant is reported as using ethylene glycol. Ether, volatile mineral spirits, and glycerine are other azeotropic possibilities. Potassium carbonate is sometimes used as an adjunct agent.

Ether is a suitable azeotropic agent only under higher pressures (about 100 p. s. i. gage), and requires equipment of special design and increased structural strength. An experimental unit using the ether process is in operation at the Northern Regional Research Laboratory, Peoria, Ill. In this process advantage is taken of the higher pressure conditions existing in the anhydrous distillation unit to reboil water from the condenser located at the top of the distillation column, thus generating low-pressure steam ( $\pm 5$  p. s. i.) which is utilized in concentrating the dilute alcohol fed to and entering the regular distilling columns. (See figure 4.) In all the azeotropic processes the volatile organic agent is continuously recovered and fed back into the system for reuse. Alcohol concentrations of about 99.6 percent are obtained.

It also is possible to dehydrate 95-percent alcohol by the use of anhydrous metal salts. These salts do not dissolve in the alcohol but merely absorb the water to form hydrated metallic salts, that is, they take on water of crystallization. Copper sulfate originally was used, or calcium salts (quicklime, gypsum, etc.). One American commercial installation apparently has operated successfully with a fused (eutectic) mixture of potassium and sodium acetate (Hiag process). This process has been employed extensively abroad. The use of aluminum oxide for similar purposes has been patented and was tried at one plant in the United States. After withdrawal of the dehydrated alcohol, all such salts can be dried to anhydrous form for reuse. Other patented methods include vacuum distillation.

These processes ordinarily add about 3 cents to the cost of each gallon of anhydrous alcohol to cover labor, capital expense, chemical losses, and steam. There is a 5-percent shrinkage in gallonage as a result of the concentration achieved. The processes usually are patented and many such patents have been in effect; however, many of these now have expired. Present production capacity in the United States is



computed at around 11 million gallons of anhydrous alcohol per year. The development of anhydrous alcohol production is largely associated with the development of the automobile. Its use originated abroad principally because of the use of alcohol in gasoline as fuel. Ordinary 95-percent alcohol is difficultly soluble in gasoline and the two, when used in blends, tend to separate, whereas anhydrous alcohol and gasoline ordinarily are completely miscible. Anhydrous alcohol also was suitable for use in the nitrocellulose lacquer finishes which were developed originally for specific use in automobile decoration. Future use in this country of alcohol in motor fuel in the form of alcohol-gasoline blends might require expansion of production capacity.

### BUTANOL-ACETONE PLANTS

In the group of plants which produce butanol and acetone by fermentation methods, grain, molasses, and (recently) potatoes have been used alternatively as raw materials, depending upon relative price or accessibility. Instead of yeast, certain bacteria (species of *Clostridium*) are employed as fermenting agents, the original process having been developed by Weizmann in England during World War I. In the butanol process ethyl alcohol in varying amounts is produced as a byproduct along with the desired chemical products. The following tabulation indicates the usual ranges of yields of butanol fermentation products from corn and molasses:

Product:	(Percent by volume of total solvents produced)	
	Corn	Molasses
Butanol.....	56 to 60.....	68 to 72.
Acetone.....	30.....	29 to 25.
Ethyl alcohol.....	14 to 10.....	3 to 8.
Mixed solvents.....	15.5 pounds per bushel.	3.5 pounds per gallon.

However, in some instances fermentation butanol plants may operate simultaneously (or alternatively) as ethyl-alcohol plants, since practically all the equipment is suitable for either process. Consequently, when comparative prices favor butanol, these plants actually may produce only the minimum (byproduct) ethyl alcohol output, while conversely, with poor markets or low prices for butanol (or acetone), they might operate wholly for ethyl alcohol production, if such production were economic. Therefore, the amount of ethyl alcohol drivable from this source depends on the butanol-acetone supply and requirement situation. One unit of butanol production offsets or is equivalent to about three units of possible ethyl alcohol production.

In prewar years, the operation of these plants (only five such plants exist) as a group seemingly averaged about 50 percent for alcohol and 50 percent for butanol production. Molasses use has averaged about 45 million gallons in the years 1940-44, inclusive,

with a peak of about 60 million gallons (1941), while at the same time grain was used as follows:

Fiscal year:	Million pounds	
	Corn	Wheat
1942.....	256.6	11.5
1943.....	333.1	167.1
1944.....	282.0	64.8
1945.....	292.0	0.5
1946.....	147.7	1.0
1947.....	420.4	
1948.....	143.9	(23.5, grain sorghum).

Surplus potatoes were used for butanol production during 1946-48 in at least one plant, to the extent of 355 million pounds. Cheese whey also has been used to a minor extent.

Butanol now is produced commercially by synthesis from waste gases of petroleum refining, from natural gas, and from acetylene or ethyl alcohol, in competition with the fermentative production. Such production is not limited to the fermentative product, *N*-butanol (normal butanol), but isomeric forms (iso, secondary, and tertiary butyls) also are produced.

Secondary butyl is produced from petroleum gases in three plants. A fourth plant is expected to begin operations in 1948. This alcohol is used to make methyl ethyl ketone and other secondary ketones and esters. Tertiary butanol is produced in one plant in California from petroleum byproducts. Isobutyl alcohol occurs as a byproduct of methanol synthesis, in at least two plants. One additional plant is understood to produce a mixture of 85 percent isobutyl and 15 percent normal butyl, by synthesis. The entire production is being expanded. Butanols also occur in the byproducts of the Synthol (gasoline) process, which may constitute a further source in the future.

The total production of butanol, all types, amounts to 30 to 35 million gallons per year, of which normal butanol production has constituted around 60 to 72 percent (139 million pounds in 1947). Of such normal butanol, about 80 percent was made by fermentation of carbohydrates (previous to 1944), the remaining 20 percent being made synthetically from ethyl alcohol (through acetaldehyde by aldol condensation). Recently, synthetic production has approached 50 percent of the total normal butanol. Other isomeric forms of butanol are: isobutanol (formerly representing 1.8 to 4.4 percent of total butanol produced), secondary butanol (representing 24 to 34 percent of total butanol), and tertiary butanol (representing about 1.4 percent of total butanol).

## SUMMARY OF ORIGINS AND APPLICATIONS

The alcohol produced by yeast fermentation from any starch- or sugar-bearing agricultural crop or crop byproduct inherently is suitable (assuming adequate rectification) for practically any industrial purpose for which alcohol is employed. Practically no limitations to such use exist and source material or use may be interchangeable, consequently, all alcohol from such materials may be pooled for use. The only restrictions on the use of industrial alcohol produced from farm crops, particularly cereals, that might be of significance are in the

actual supply of these raw materials and the factor of relative cost, since the same alcohol can often be produced more cheaply from other materials which also may be available in sufficient quantities. In the production of beverage alcohol the field narrows to a few specific agricultural raw materials (cereals), and cost becomes less of a major consideration. With suitable and usually not too extensive plant additions, any existing fermentation plant can be adjusted to handle any potential raw material.

For most industrial uses, ethyl alcohol obtained synthetically from petroleum or other sources or produced by fermentation of sugars derived from the cellulose of wood, likewise can be used. However, for certain industrial uses (as cosmetic ingredients, for example), and for others involving subsequent internal consumption of the alcohol by human beings (as pharmaceuticals, flavorings, etc.), alcohol from nonfermentation sources may meet consumer prejudice. In the use of alcohol for antifreeze, general chemical manufacturing operations, synthetic rubber, munitions, or motor fuel, distinctions as to origin are not significant technically and alcohol from any source may be used.

Extensive use of potatoes, fruit, cane sorghums, citrus wastes, sugar-cane tops, cacti, and wastes from starch factories, canneries, and the like as sources of industrial alcohol is relatively unlikely in normal times, for economic reasons. In the case of sulfite pulp mills, and perhaps in other instances, the effect of stream pollution laws may cheapen such sugar sources to competitive levels, when waste disposal costs are considered.

## FINANCIAL ASPECTS OF ALCOHOL PRODUCTION

### PLANT COSTS

Since fermentation alcohol plants usually differ from each other in equipment details and space arrangements, and since production techniques vary considerably, no wholly accurate, generally applicable basic investment cost can be formulated. In general, plants utilizing molasses operate on a comparatively simple process and require less equipment than grain plants; grain handling and byproduct feed recovery operations ordinarily being omitted, and steam requirements being less. Under former normal price scales,<sup>20</sup> the capital investment cost of a plant that used molasses only, producing 10,000 gallons per

<sup>20</sup> The text of this bulletin has been prepared during a period when labor, equipment, building, and raw material costs are inordinately high. Such costs eventually may decrease, but the future level of stabilization is a matter of conjecture. Since the available data on which conclusions in this text are based were derived in the prewar and early wartime periods, the general levels thus indicated have been considered as normal conditions, in contradistinction to present conditions, which are considered to be abnormal. Therefore, the normal values used are not realistic, as of this date, and must be adjusted accordingly, now and in the future. The computations might have been made at levels more nearly approximating present conditions, but these might become similarly non-realistic in the future. As an example, alcohol prices fell from around 75 cents per gallon in October 1948 to 17 cents in February 1949. Hence it has seemed more advisable to adhere to known historical price levels, as a basis. Also, throughout this text, it has been the intention to reflect conservative values, attainable by the general run of the industry, rather than high (special condition) values obtainable in the best or most modern plants.



day, approximated \$50 per wine gallon of daily output of 190-proof alcohol. Actual investment varied from \$35 per gallon for a very simple plant to \$75 or more for a modern, well-built plant fully equipped with instrument controls and labor-saving facilities. Under present conditions the costs will be much greater. Over-all costs decrease proportionately with increase in output capacity.

It has been estimated (40) that former plant costs, based on book value of undepreciated buildings and equipment, at construction or acquisition costs, exclusive of land, averaged:

	<i>Capital cost per wine-gallon, an- nual capacity of 95-percent alcohol</i>	<i>Annual capacity (wine gallons)</i>
Small plants (group of 7)-----	20 cents---	1, 075, 500
Medium plants (group of 3)-----	10.8 cents--	9, 284, 100
Large plants (group of 2)-----	4.3 cents--	53, 000, 000

This computation presumably does not distinguish between grain or molasses plants, and may include both types.

Grain-using industrial-alcohol plants and distilled-spirits plants of similar size formerly cost from \$50 to \$150 per wine gallon of daily output. The lesser figure represents old-style plants with wooden, open-top fermenters, comparatively simple grain-milling equipment, open mash-tub (atmospheric pressure) cooking, and the recovery of spent-grain screenings only. The higher figure represents a modern distilled spirits plant featuring controlled milling with grain degermination, pressure cooking, recovery of high-grade alcohol in higher concentrations, and complete recovery of fermentation byproducts. Such a plant would be extensively equipped with instrument controls, would be largely automatic in operation, and would possess adequate control and research laboratories. In distillery construction a considerable amount of additional expense is represented by the warehouses required for storing and aging spirits and by facilities for packaging in glass. These are not needed for industrial alcohol production. Under normal conditions it is believed that a satisfactory industrial alcohol (grain) plant of this size probably could be built for approximately \$100 per gallon of daily output. It may be possible to reduce costs in future years through plant simplification. Plants of larger capacities cost progressively less.

A break-down of the cost of a new, large, modern alcohol (grain) plant built in 1943-44 under wartime conditions at Government expense, is shown in table 7. This table indicates approximately the relative expenditures for various plant essentials, on a percentage basis.

TABLE 7.—*Percentage of costs of modern industrial alcohol plant*

Item	Percentage of total cost <sup>1</sup>
	<i>Percent</i>
Land, improved.....	0. 66
Buildings (all).....	36. 13
Building installations (nonmechanical).....	3. 83
Leasehold improvements, services.....	4. 72
Contractors and architects fees, etc.....	7. 96
Total for nonequipped plant.....	53. 30
Machinery and equipment (partly installed).....	36. 30
Installation expenses, additional.....	9. 52
Tools, etc.....	. 42
Furniture and fixtures.....	. 32
Laboratory and testing equipment.....	. 14
Total for equipment.....	46. 70

<sup>1</sup> To the extent that individual processing steps can be identified, the cost of the drier house of the plant represented 37.0 percent of the total investment and the boiler house represented 22.7 percent (3,500 hp.).

Further analysis reveals the following over-all summaries:

Over-all investment cost per daily wine gallon of alcohol output.....	\$77. 00
Over-all investment cost of boiler facilities per boiler horsepower.....	175. 00
Over-all investment cost of dry house, per daily ton of feed produced (including proportionate share of boiler costs).....	9, 110. 00
Over-all nominal installed steam capacity, per bushel of grain processed.....	220 pounds

In normal times this plant presumably might have been erected for approximately 70 percent of the actual cost. The boiler plant expense was relatively very high, owing to special conditions. Since this plant represented an output capacity of perhaps four times the plant size previously considered herein as average, the investment saving owing to increase of size is clearly indicated.

### EQUIPMENT REQUIREMENTS

Building and equipment requirements for alcohol plants can be listed generally as follows. This list must be modified to fit individual circumstances in any specific case. Great latitude exists as to the use of smaller supplementary items (pumps, control instruments, etc.), hence it is impractical to list these in detail.

### ALCOHOL-PLANT EQUIPMENT REQUIREMENTS

Railroad facilities: Sidings, docks, track and truck scales.  
 Raw material handling: Unloading, weighing, cleaning,<sup>1</sup> storing, conveying.  
 Buildings:  
     Offices.  
     Repair shops.  
     Locker rooms, first-aid room, watchmen's gate house, etc.  
     Pumphouses.  
 Services: Water, sewers, etc.

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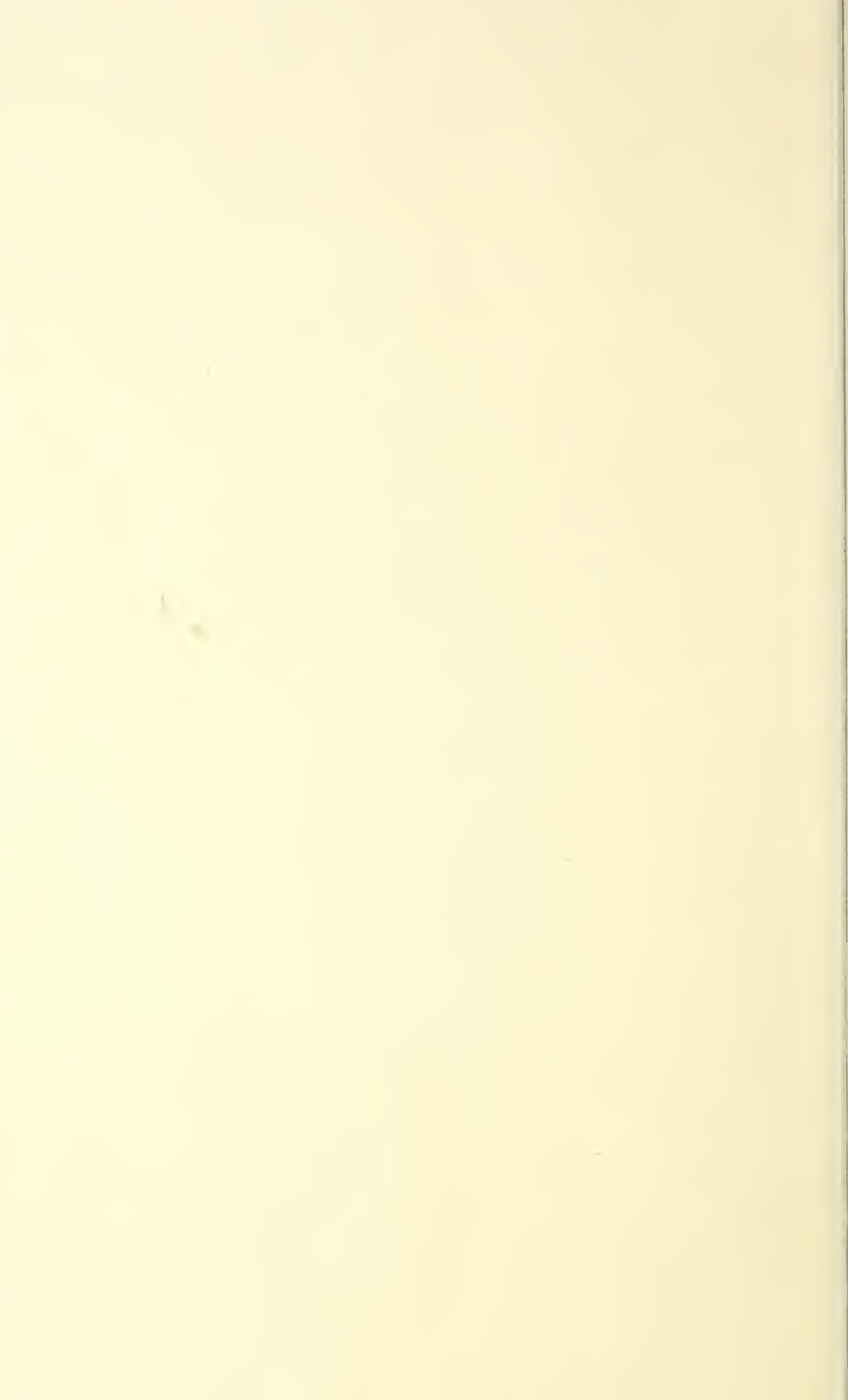
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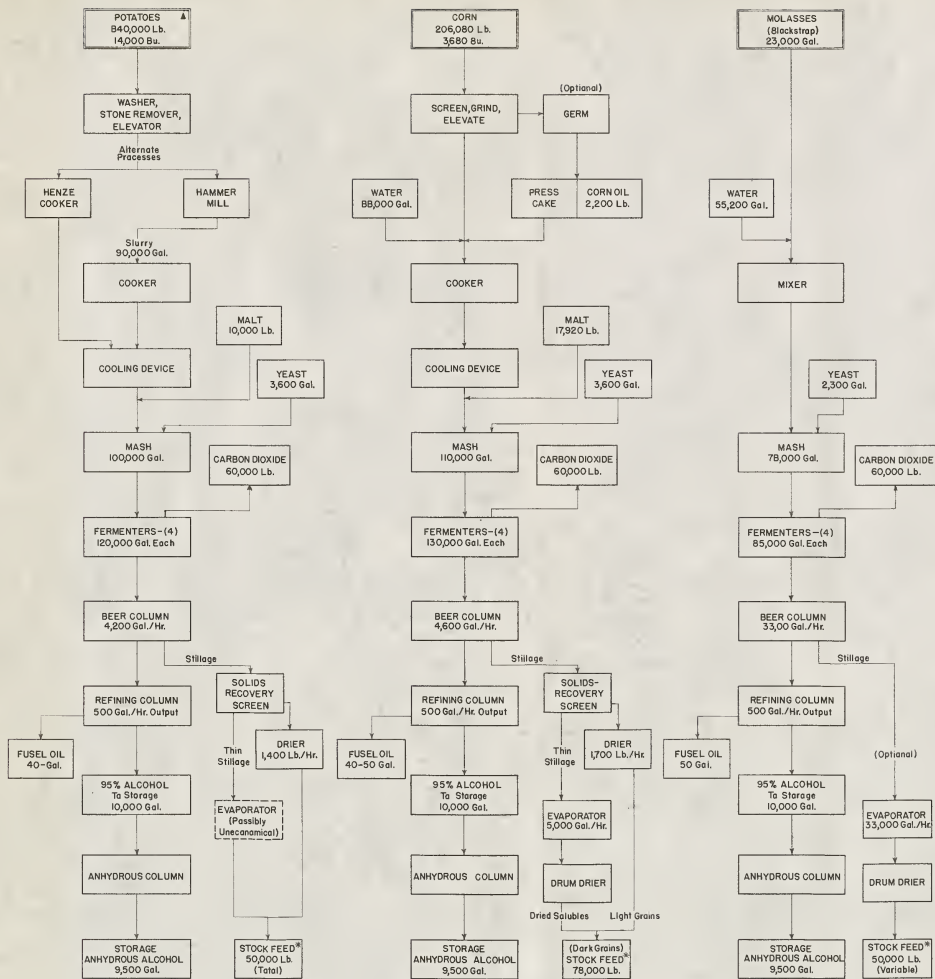
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FUSEL OIL  
40-Gal.







A 15 Percent Fermentable Matter Or 20 Percent Solids

\* 10 Percent Moisture Basis

Figure 1.—Conventional alcohol process

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Boiler plant (to be physically separate from all other buildings):

- Fuel and ash handling.
- Condensate return, feed water heaters.
- Water treatment.
- Control, recording instruments, and accessories.
- Dynamo, air compressor, meters, motors, switchboards.

Fermenting (all stages may be housed in one building):

- Grain milling.<sup>1</sup>
- Cooking apparatus.<sup>1</sup>
- Malt (or other saccharifying agent) preparation.<sup>1</sup>
- Yeast preparation units.
- Mash coolers.
- Fermentation vessels.
- Drop tubs (beer wells).
- Carbon dioxide scrubber.
- Hot water storage (reuse).
- Mash pumps.

Distilling (much equipment might be located in the open, with controls housed in single building. This depends on prevailing outside temperature and other conditions):

- Beer and slop pumps.
- Beer column and condensers.
- Aldehyde or "heads" column.
- Rectifying column.
- Stripping column (optional).
- Anhydrous column (if desired).
- Accessories, control panel, recording meters, etc.
- Process tanks (alcohol).

Alcohol storage (bonded warehouse, to be physically separated from distillation plant. Reserve tanks may be located in the open): Alcohol scales, pumps, etc.

Stillage recovery <sup>1</sup> (in separate building):

- Screens.
- Presses.
- Driers (inclined rotary type, preferably steam heated, for screenings).
- Evaporator.
- Sirup storage tank
- Mixing device (to combine sirup and dried screenings for redrying—to produce dark grains).
- Drum or spray driers for evaporating sirup (alternative to mixing).
- Pumps.
- Recorders, accessories.
- "Grains" bins.
- Bagging chute.
- Scales.
- Stillage tanks.

Control laboratoes, yeast laboratories.

Denaturing plant (to be physically separate from distillation plant): Storage tanks, scales, pumps.

Storage space, for drums or cans (new supply).

Loading docks.

<sup>1</sup> Items not needed for molasses plants. Usually no stillage recovery equipment is included in such plants, and boiler plant capacity is less than for grain plants.

Flow diagrams, showing approximate quantities of material and capacities of equipment for three comparable plant processes are shown in figure 1. These diagrams are based on the processing of white potatoes, corn, and molasses. They show variations in amounts of necessary raw material, required general equipment, and products

of the three basic materials, for an identical production of 10,000 gallons of 190-proof alcohol per day. Assumptions made in this computation are related to the usual commercial raw materials and practice, but may not necessarily fit the conditions for any specific



FIGURE 2.—Grain handling and milling equipment.



plant. Relative steam requirements can be deduced by inference from the procedures indicated.

Types of equipment and suitable method of arrangement are illustrated in figures 2 to 6 inclusive, which show views of the alcohol-production pilot plant erected at the Northern Regional Research Laboratory, Peoria, Ill. This plant has a capacity for processing about 200 bushels of grain daily, yielding around 500 gallons of anhydrous alcohol. It will be noted that the plant utilizes gravity flow systems wherever possible.

Figures 2 and 3 show the grain receiving, elevating, milling, cooking, and fermenting systems. Equipment for two stages of yeast preparation also are visible (upper floors, to right of cooker, fig. 3). The

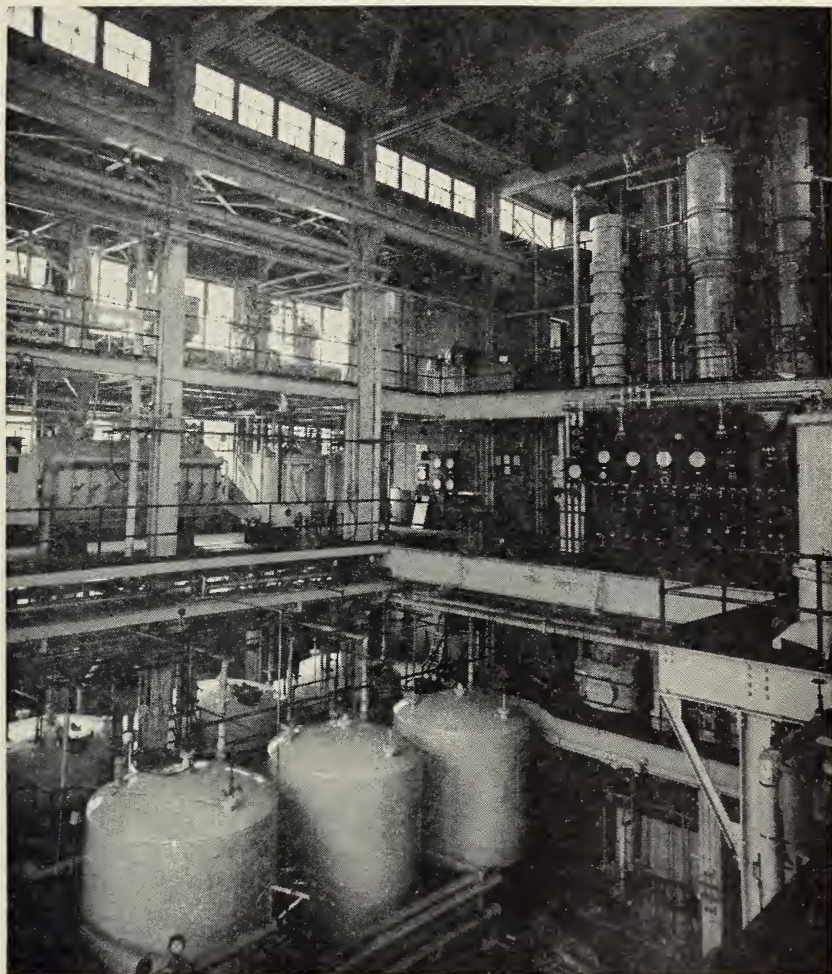


FIGURE 3.—Cooking, yeasting, and fermenting equipment.



grain handling equipment (to the left in fig. 2) is linked together by automatic controls so that the entire system stops as a unit if trouble occurs anywhere in the system. Cooking may be done by the ordinary batch and pressure method (horizontal cooker, second floor, fig. 3), or in the Henze pressure cooker (cooker No. 2, fig. 2) applicable particularly to handling potatoes. Continuous-jet pressure cooking methods can also be utilized, but equipment is not shown. Atmospheric cooking may also be done in the pressure cookers, therefore, this plant is not provided with the open mash tuns ordinarily used by certain older plants. The malt slurry and reuse stillage and the yeast are run by gravity to cookers and fermenters, respectively.

Figure 4 shows the distilling apparatus. Fermented mash (beer)

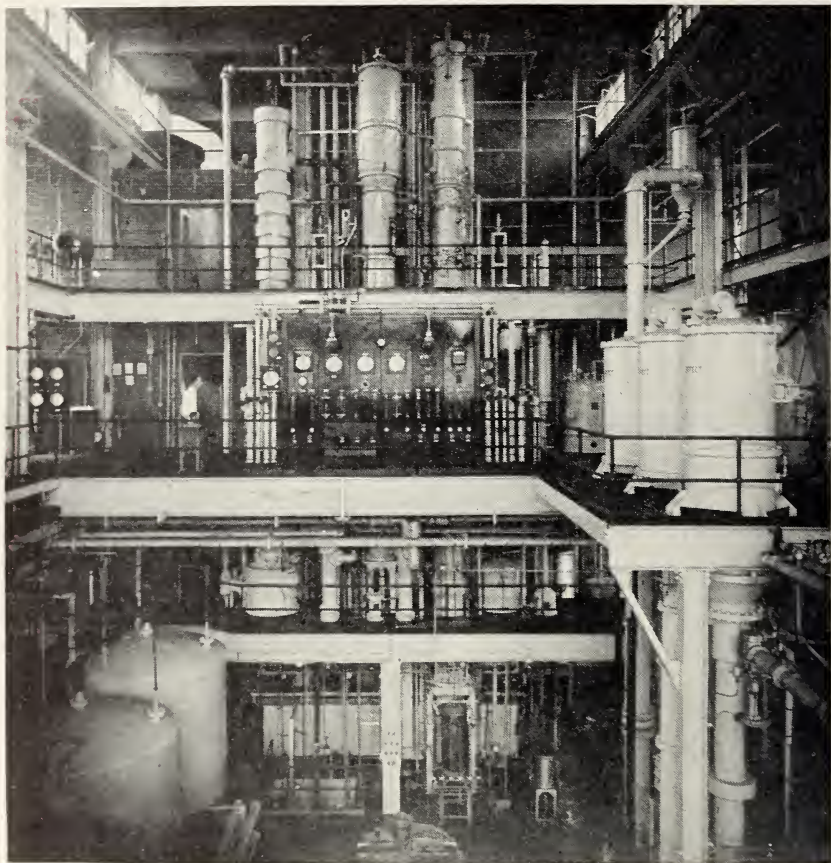


FIGURE 4.—Distillation equipment.

from the fermenters is pumped to the top of the left hand (beer) column, free steam being blown upward through it as the liquid descends. Weak alcohol vapors issue from the top of this column and pass to the large (middle) column where aldehydes are removed through the top (horizontal) condenser. The refined, concentrated

alcohol vapors pass to a small column (hidden) located between the beer and the middle column, and are further rectified and then condensed. The cooled alcohol (at 95- to 96-percent concentration) goes to a storage room located behind the screen partition (rear of distillation columns). To make anhydrous alcohol, this 95-percent alcohol subsequently is fed to the right-hand column and distilled at 100 p. s. i., ether being continuously added. An ether-water-alcohol fraction is continuously distilled off, settled in a small tank (shown to right), and the ether distilled off by means of the very small column to the right

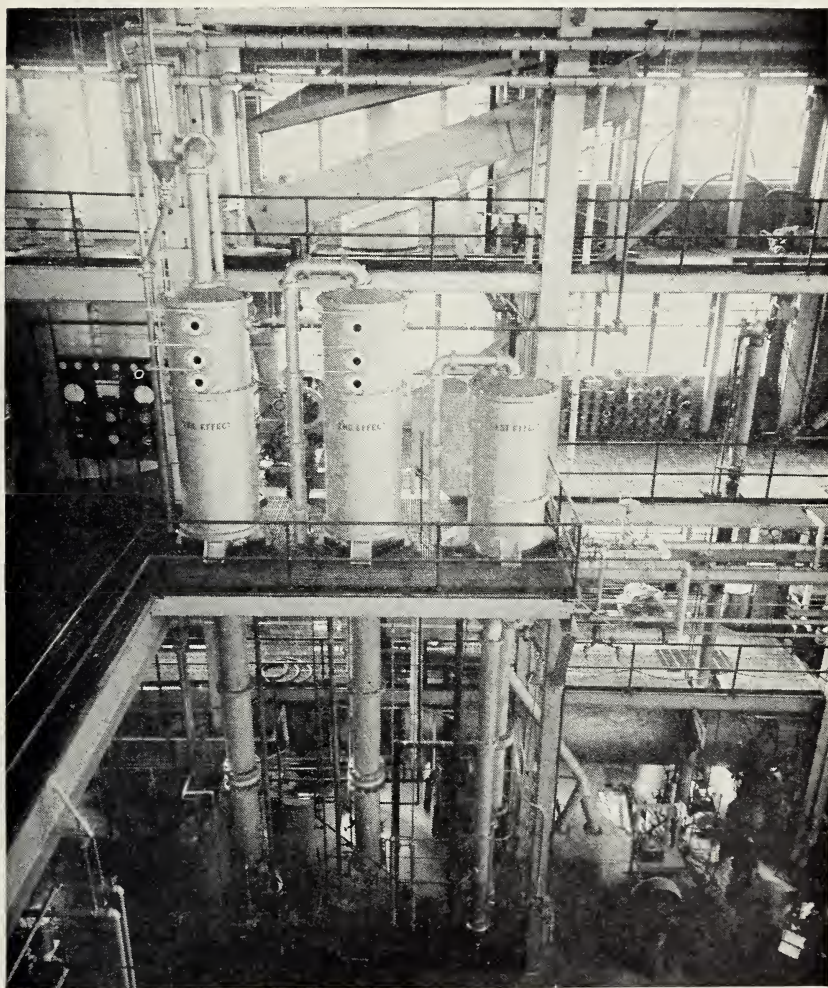


FIGURE 5.—Residues recovery equipment.

of the anhydrous column. Fusel oil is recovered from lower plates of the middle (aldehyde) column, and fractionated in a small column (hidden behind control board). All weak alcohol fractions from any phase of the process are returned to the rectifying column.



The hot (dealcoholized) liquor (stillage) from the beer column discharges from the pot base, passes through heat exchangers, and is pumped to the feed recovery section of the plant.

Figure 5 shows the feed recovery installation. The warm stillage from the beer still heat exchanger is pumped over the inclined screen situated on the upper floor. Liquids from the screen are collected in a wooden tank on the first floor (not visible), and are pumped continuously to the triple effect (Swenson) evaporator (foreground) for concentrating. Sirup from the last effect is pumped to a sirup storage tank (upper floor, behind screen box).

Solids from the screen fall through a rotary (dewatering) press (second floor behind evaporator), and thence to an inclined tubular steam drier (first floor, behind evaporator). These dried solids (so-called light grains) can be blown to bins on the second floor (behind

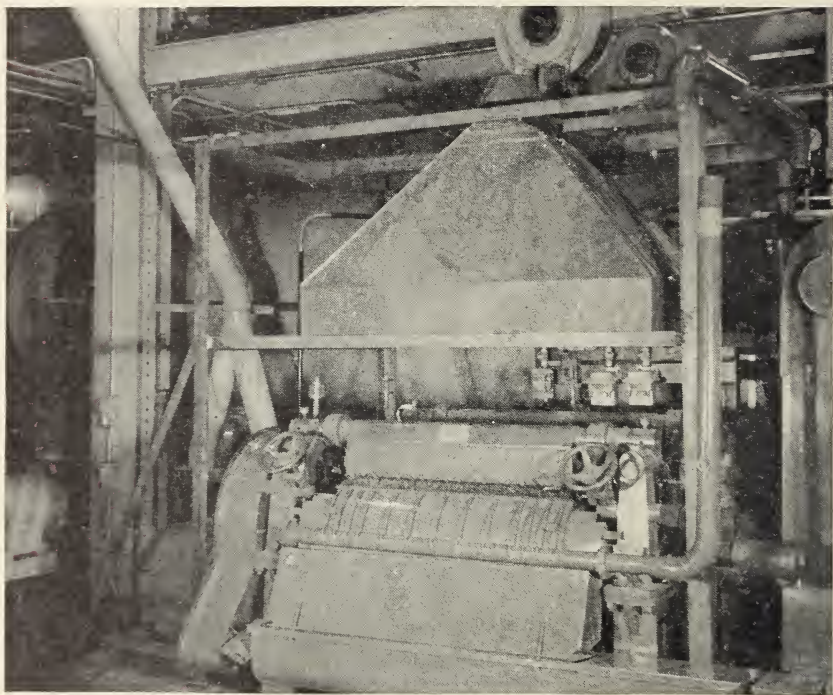


FIGURE 6.—Drum drier.

evaporator). These dried solids can be dropped through a mixer (first deck, not visible), where sirup from the storage tank may be added, the wetted material then being repassed through the steam tube drier for redrying. This product is known as dark grains. Alternatively, the sirup from the storage tank can be dried separately on the drum drier (fig. 6, located on the first floor), as dried solubles.

This plant utilizes the conventional equipment usual to modern alcohol plants. It was designed for research on alcohol production on the basis of conventional practice, so that the data obtained would



be easily translatable to present large-scale equipment. Practically every piece of equipment in this plant is well provided with control instruments, so that in lieu of operation of the entire plant, unit operations for each item of equipment may be studied.

### PATENT SITUATION

Owing to the age of the industry, most basic patents on the alcoholic fermentation and distillation processes have expired. Patents on specialized equipment usually are owned by the equipment manufacturers and purchase of such equipment ordinarily carried with it the right of use. Patents are still in effect on anhydrous-alcohol production methods, but some of these will expire soon. The patent situation seemingly does not present any real obstacle to operation or expansion of the industry. During the war, originators of processing improvements, which perhaps may be patented eventually, allowed free use by all producers as a patriotic gesture. The patents covering production of synthetic alcohol might constitute effective limitations on such production.

### ALCOHOL PRODUCTION COSTS

The cost of producing alcohol depends on the location of the manufacturing plant; the design, type, and degree of modernization of equipment; the kind of raw material used; the price paid for the raw material; the relative labor costs represented; the scale of production; the level of recovery and returns obtainable; and the total investment. It should be emphasized that no definite or fixed alcohol cost exists; costs will vary between similar plants, and even from day to day in the same plant. Operation costs have fluctuated widely during recent years. It was estimated that, under the conditions which existed about 1938, the plant-operating (conversion) cost of producing a gallon of 95-percent alcohol from blackstrap cane molasses might be as low as 3 to 4 cents per gallon (exclusive of raw material) for a unit operating at the highest efficiency and producing from 20,000 to 30,000 gallons of alcohol per day. Normally, for smaller or less efficient operations, the cost may exceed 6 cents. Computing blackstrap molasses at the 5 cents per gallon price ordinarily current before the war, and assuming a yield of 1 gallon of 99.5-percent alcohol from 2½ gallons of molasses, the operating and raw material costs might approximate 18½ cents per gallon of alcohol under good operating conditions (15, p. 52).

The net operating (conversion) cost of producing alcohol from corn in economically sized plants (10,000 to 20,000 gallons daily capacity) for normal price periods might be estimated (15, p. 56; 34, p. 14) as ranging ordinarily between 7 to 13 cents per gallon. This is based on use of a malt percentage of 8 percent of the grain mashed. (Malt costs may represent an expense of 5 to 11 cents per gallon of alcohol produced, depending on the percentage used and the current malt price.) Such estimate includes ordinary byproduct feed and fusel oil recovery only, as offsetting credits. Assuming a corn price of 45 cents per bushel delivered at plant (possibly representative prewar price for grades of grain used in distilling), a presumably comparable malt

price of \$1 per (34-pound) bushel, the use of 8 percent of malt, a yield of 2.5 wine gallons of 95-percent alcohol per bushel, and a net credit value of 16.25 cents for the byproduct feed ordinarily recovered from each bushel of grain,<sup>21</sup> the total (net) plant operating and raw material costs of alcohol can be estimated at approximately 30 to 32 cents per gallon, in plant storage tanks (unsold, without profit). Relative changes in alcohol cost, with increasing grain prices, are indicated approximately in table 8.

TABLE 8.—*Relation of alcohol cost to grain price*<sup>1</sup>

Corn, cost per bushel	Corn, cost per wine gallon of alcohol	Estimated comparable malt cost per gallon of alcohol	Total raw material cost per gallon	Estimated net cost of alcohol (calculated values)
<i>Dollars</i>	<i>Cents</i>	<i>Cents</i>	<i>Cents</i>	<i>Cents</i>
0. 56	20. 60	7. 2	27. 80	34. 04
. 65	23. 98	7. 2	31. 18	36. 26
. 85	31. 23	9. 0	40. 23	42. 16
1. 00	36. 77	9. 0	45. 77	46. 10
1. 25	46. 00	10. 8	56. 80	53. 41
1. 55	57. 02	10. 8	67. 82	59. 74
2. 00	73. 60	12. 0	85. 60	69. 84
2. 50	92. 20	12. 0	104. 20	79. 40

<sup>1</sup> Use of 92 percent corn, 8 percent malt assumed, all values on sliding scale.

These estimates do not include sales costs, packaging expense, freight allowances, or costs of subsequent denaturing. Profits to the producer and retailer and general corporation overhead must be added, to determine the price per gallon to the consumer. These figures are merely typical and will vary with conditions. Cost figures reported in the past have varied greatly, particularly since some companies separate certain overhead, management, byproduct recovery, or supervision cost items from actual plant operating costs, so that the apparent conversion costs are lower than reality. Also in some computations (22) the costs have been based on denatured alcohol rather than on straight alcohol, thus deriving credits from denaturing operations. During the past few years operating costs have increased notably, particularly for labor. In the case of grain, with high percentages of recovery of products and byproducts, good market returns, and low cost operation, the returns from the byproducts conceivably might equal the entire production cost (exclusive of raw material) as a general optimum. However, it is doubtful if this has been achieved heretofore, except for short periods under very favorable circum-

<sup>21</sup> Byproduct feed values and malt costs will vary with changes in grain price levels. Although the grain and malt prices used seemingly are low, if alcohol sales values were to stabilize at about the indicated level, these grain values may represent the economic limitation.

stances. At high recovery levels and good prices, the value of the byproducts ordinarily should be sufficient to offset practically all plant operation costs exclusive of general overhead (which usually approximates 2 to 3 cents per gallon). Very large plants can achieve significant reductions in gallon cost, particularly for general expenses, as a result of large output. Recovery of corn oil, carbon dioxide, etc. can reduce over-all costs, at times.

The size of the plant and amount of production will have a definite bearing on cost of operation. Alcohol production costs tend to increase as the total production decreases. In general, the conversion costs for plants of relatively small output (2,500 to 6,000 gallons per day) have ranged from perhaps 2 to 10 cents per gallon above those in very large plants. This is in part because of relatively higher overhead costs per gallon, and also because existing smaller plants frequently are of older construction and often lack proper facilities and organization to obtain high yields or efficient operation. A new plant of modern type, even though of relatively small output, might compete on production costs more successfully if the proper design and organization are provided. A certain amount of general overhead (supervision, chemical and bacteriological plant control, etc.) is essential to achieve efficient operation. Instrumentation necessary to such control increases capital costs. Other overhead items such as taxes, sales expenses, contributions, etc. likewise must be met. If the plant output is small, the per gallon expense of this overhead runs proportionately higher. If adequate supervision and control are not provided, yields are likely to suffer.

A daily output of 2,000 wine gallons seemingly might represent a minimum operation unless special favoring conditions exist, for example, when part of the costs can be charged to other manufacturing operations. At the other extreme, plants producing 20,000 to 30,000 gallons per day can carry considerable overhead, even including social services (cafeterias, pensions, etc.) and yet the total charge incurred per gallon is relatively small. The large plant, however, while far more economical of operation—when actually operating—is at a corresponding disadvantage under reduced or suspended operation, and it may require a larger sales organization because of the necessity of entering markets over a wide area. Continuance of material supply is usually a greater problem for the large plant, which must operate over a much greater raw material supply radius. Hence, operations based on a relatively local supply of raw material or on local sales outlets must be geared to a proper relationship of such supplies and markets. A plant of 10,000 gallons per day minimum output has been considered herein as representing a reasonable compromise among all the factors, for purposes of this discussion.

A tentative general itemization of processing costs for a complete grain-using plant is shown in table 9. Variations from the cost figures shown may be expected, and the net final cost of the alcohol may vary as much as 5 cents or more per gallon from the computed values shown.



TABLE 9.—*Processing cost of producing alcohol from corn*<sup>1</sup>

[Basis 10,000 gallons of 95-percent alcohol per day for 300 mashing days per year, or 3 million gallons per year. Required: 1,104,000 bushels corn and 158,180 (34-pound) bushels malt. Plant cost assumed to be \$850,000. Total grain and malt used—4,000 (56-pound) bushels per day, 6 days' operation per week]

Item	Annual cost	Cost per gallon
Plant overhead, depreciation, property taxes, bonds, licenses, insurance, social security, workmen's compensation, etc.....	<i>Dollars</i> 153, 000	<i>Cents</i> 5. 10
Salaries (management, office, laboratory—17 persons).....	61, 600	2. 05
Labor, plant and maintenance (60 men).....	150, 000	5. 00
Office expense, laboratory operation, freight and drayage, donations, miscellaneous.....	30, 000	1. 00
Water, electricity, fuel, fire protection, etc.....	75, 000	2. 50
Chemicals and supplies, maintenance materials.....	30, 000	1. 00
Actual conversion (manufacturing) expense (including dryhouse operation and shipping labor).....	499, 600	<sup>2</sup> 16. 65
8 percent malt at \$1 per (34-pound) bushel.....	<sup>3</sup> 158, 100	5. 27
Total cost, exclusive of corn.....	657, 700	21. 92
Less credit for feed byproducts (full recovery) per gallon (6.5 pounds at 1.5 cents per pound, net) plus 0.37 cent for fusel oil.....		10. 12
Over-all net conversion cost (excluding corn).....		11. 80
Add for profit and contingencies.....		4. 20
Total cost, for conversion and profit.....		16. 00

<sup>1</sup> Tentative estimate, realistically based on a theoretical plant, small-town location, semiunion scale (*circa* 1942). Practically all of the separate cost items will vary with local conditions. With advantageous conditions, actual production for the same labor organization might be considerably increased by relatively small increases in capital investment to provide essential equipment. With equipment of very modern design, including some automatic control features, savings of several cents a gallon might be possible through reduction in labor and supervision costs. Recovery of carbon dioxide and/or corn oil might provide additional credits of 1 to 5 cents a gallon. All sales or shipping costs (except labor) must be added, as well as any general office overhead. Actual feed by-product values will vary with grain prices.

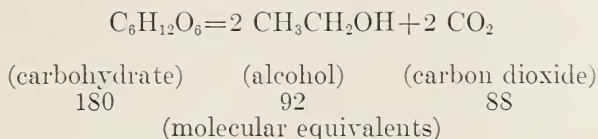
<sup>2</sup> These costs will be relatively stable for any plant, all other costs will vary widely.

<sup>3</sup> Malt ordinarily is considered as raw material, since some alcohol is produced therefrom. It is shown here as a conversion cost item, to emphasize the significant added cost which might be saved in part, by perfection and substitution of other saccharifying agents. Malt cost will vary with grain cost levels.

### YIELDS

Methods of computation of the probable yields of alcohol and by-products from various materials are based on the following data:

Carbohydrates break down under fermentation according to the general chemical equation—



This means that 180 pounds of carbohydrate theoretically should yield 92 pounds of alcohol and 88 pounds of carbon dioxide gas. In the case of molasses, or any substance containing only sugars, the theoretical yield of alcohol is 0.511 pound for each original pound of invert sugar present, or 0.538 pounds of alcohol for each original pound of sucrose. For starch the theoretical yield of alcohol will be 0.568 pound. Differences in theoretical yields are owing to the fact that higher carbohydrates take on water in hydrolysis, yielding slightly greater amounts of simple sugars. In actual practice, the efficiency of conversion to alcohol usually is only about 85–88 percent from starch and 90–92 percent from sugar, the remainder of the fermentable material either being recovered as byproduct, or lost. Hence, if the chemical analysis of any given raw material is available, the potential products can be computed with reasonable accuracy.

Carbon dioxide production can be estimated as follows: 1,000 wine gallons of anhydrous alcohol (6,610 pounds) produced from glucose, for example, theoretically will also yield  $\frac{0.489}{0.511}$  or 6,325 pounds (3.16 tons) of gas as a byproduct.

Byproducts of the fermentation process, such as feeds, represent the unfermented residue of the original raw material (from which only starch and sugar theoretically are removed by the fermentative action), plus the products from the growth of yeast in the solution and the chemicals added for yeast stimulation.

Corn, for example, although showing some differences among varieties, and for various years, may be assumed to have an average (commercial grade) composition about as follows: <sup>22</sup>

Constituent	Composition of corn	
	1941 crop, percent	1947 crop, percent
Starch.....	60.70	61.70
Free sugar.....	1.51	1.77
Protein.....	9.32	8.86
Fat (oil).....	3.85	3.70
Fiber (by difference).....	9.95	8.72
Ash.....	1.17	1.25
Moisture.....	13.50	14.00

Therefore, a 56-pound (distillers') bushel ordinarily may contain approximately 34 pounds of starch, 0.8 pound of sugar, 5.2 pounds of protein, 2.2 pounds of oil, 7.5 pounds of moisture, and 6.3 pounds of fiber, ash, and other chemical constituents related to the plant structure. Varieties showing higher starch content usually represent better maturity and may have the remaining percentages correspond-

<sup>22</sup> Average of No. 2 yellow, received at markets (Iowa, Nebraska, Minnesota, Illinois, and Ohio) in 1941 and 1947.

ingly lowered or changed. Other grains have similar general composition but differ in the percentage of each constituent.

Alcohol yields usually being in direct relation to starch content, the potential yields are shown in table 10.

TABLE 10.—*Alcohol yields from grain*<sup>1</sup>

Starch in grain (as received)	Starch per bushel	Alcohol per bushel (theoretical)	Alcohol per bushel (theoretical)	Alcohol, <sup>2</sup> basis 90-percent recovery
<i>Pct.</i>	<i>Lb.</i>	<i>Lb.</i>	<i>Wine gal.</i>	<i>Wine gal.</i>
65	36.40	20.67	3.127	2.81
64	35.84	20.36	3.07	2.77
63	35.28	20.04	3.05	2.72
62	34.72	19.72	2.98	2.68
61	34.16	19.40	2.91	2.63
60	33.60	19.08	2.86	2.59
59	33.04	18.76	2.81	2.55
58	32.48	18.45	2.76	2.51
57	31.92	18.13	2.72	2.47
56	31.36	17.81	2.67	2.42
55	30.80	17.49	2.62	2.38
53	29.78	16.85	2.53	2.30

<sup>1</sup> Standard distillers' bushel of 56 pounds. <sup>2</sup> Anhydrous alcohol basis.

Apparent recoveries of residuals, as computed from representative analyses of various grains, should be about as shown in table 11.

TABLE 11.—*Unfermentable residues from grain*<sup>1</sup>

Material	Probable percent original grain unfermentable	Probable minimum amount per 56-pound bushel (dry basis)
	<i>Percent</i>	<i>Pounds</i>
Wheat.....	26.9	15.05
Corn.....	22.3	12.5
Buckwheat.....	25.0	14.0
Grain sorghum.....	24.4	13.7
Barley.....	32.3	18.1
Rye.....	27.1	15.15
Oats.....	42.3	23.7
Sweetpotatoes.....	4.6	2.58
White potatoes.....	3.8	2.13
Sugar beets.....	5.0	2.8
Apples.....	2.0	1.12

<sup>1</sup> Jacobs and Newton (15, table 3).



These percentages will vary among grain varieties, and are only approximations, representing the sum of the known constituents which are presumed to remain unfermented. The amounts will be increased by the yeast substances present, as well as by unfermented carbohydrates (dextrins, which may amount to perhaps 10 percent of the starch, or 3.5 pounds). Also, the feed is sold on a hydrated, and not on a dry basis, so that a gain of around 10 percent of moisture usually is achieved. Residues from malt employed in processing also add to the total. For example, the indicated minimum residue for corn, 12.5 pounds per bushel, represents only about 68 percent of the amount ordinarily obtainable. Actual recoverable values for other materials would be increased somewhat similarly, but to a considerable lesser degree if apples, beets, and perhaps potatoes were the raw materials used.

#### RELATIVE COSTS OF ALCOHOL FROM DIFFERENT FARM CROPS

The yield of alcohol and byproducts obtainable from various farm crops depends on the character and composition of the material and the efficiency of operation. Properly treated, fermented carbohydrate materials when distilled may yield alcohol at relative net costs somewhat as presented in table 12.

An average rather than a high fermentable-matter content is assumed in this computation, since the materials that might be used ordinarily for industrial alcohol production are not likely to be the highest market grades. The computations are based merely on the assumed relative carbohydrate content of the particular commodity plus an estimated conversion cost, with estimated byproduct credit allowances. Differences in transportation costs and general items not ordinarily included as processing costs are not considered. Over-all fermentation/alcohol recovery efficiencies of about 85 percent of theoretical are assumed, since this might represent average performance at most plants, on such materials.

Table 12 indirectly indicates approximately the relative price levels (in normal times) at which the various crops must be obtained if they are to compete in alcohol production. Although all the respective alcohol costs shown are greater than those of the molasses alcohol used as a basis, it may be seen that the prices at which the raw materials are computed are below the usual market prices and in the case of potatoes, for example, represent cull values only. In order to produce alcohol from farm crops at a cost equal to that shown for molasses alcohol, the prices paid for the various raw materials must be correspondingly reduced unless processing costs are cut or byproduct values are increased.

TABLE 12.—*Estimated relative costs of alcohol from certain farm crops in comparison with blackstrap molasses (basis, 100 wine gallons of 95-percent alcohol produced, prewar price basis)*

Raw material	Amount required (units)	Price per unit (delivered)	Raw material cost	Assumed processing cost <sup>1</sup>	Total cost	Estimated credit for byproducts <sup>2</sup>	Net cost of 100 gallons alcohol <sup>3</sup>
Molasses (blackstrap)-----	250.0 gallons-----	\$0.05 per gallon <sup>4</sup> -----	\$12.50	\$6.00	\$18.50	\$0.50	\$18.00
Apples-----	7 tons-----	\$5 per ton-----	35.00	9.50	44.50	5.00	39.50
Corn-----	40 bushels-----	\$0.45 per bushel-----	18.00	16.00	34.00	7.00	27.00
Grain sorghum-----	45 bushels-----	\$0.40 per bushel-----	18.00	16.50	34.50	4.50	30.00
Potatoes-----	140 bushels-----	\$0.10 per bushel-----	14.00	13.00	27.00	2.00	25.00
Sweetpotatoes-----	100 bushels-----	\$0.15 per bushel-----	15.00	12.00	27.00	1.50	25.50
Sugar beets-----	4.52 tons-----	\$5 per ton-----	22.60	9.00	31.60	3.60	28.00
Wheat (soft)-----	40 bushels-----	\$0.70 per bushel-----	28.00	18.00	46.00	6.10	39.90

<sup>1</sup> These costs represent the summation of a great many variables, and will differ for each plant. Malt costs are included for starch materials, but profit is omitted. Fermentation efficiency of about 85 percent of theoretical is assumed.

<sup>2</sup> Fusel oil and byproduct feed (distillers' dried grains) only. The feed values will vary with changes in cost of the original raw materials.

<sup>3</sup> These figures are the net resultant of many variables and must be considered as tentative. Byproduct feed values will be low at levels used. However, the figures shown probably reflect the relative order of alcohol cost for the raw materials and prices used.

<sup>4</sup> 5 cents a gallon is taken as a fair price for molasses, in comparison with the other potential alcohol sources. Prices of blackstrap molasses reached 37 cents per gallon in June 1948, placing this material temporarily at a disadvantage with corn at coexisting market prices. Actually, at such prices the value of the sugar in the molasses was considerably higher than the prevailing price of raw sugar, illustrating how far the blackstrap situation had become abnormal.

## POSSIBLE IMPROVEMENTS IN ALCOHOL-PROCESSING METHODS

In the past, both the distilled-spirits and industrial-alcohol industries have employed certain common, basic, and conventional processing steps, regardless of individual plant variations owing to the particular equipment used. The production process in both industries has consisted of a series of batch operations, so arranged that a continuous flow of final product is obtained. In the distilled-spirits industry experimentation with new or radically different methods has been limited somewhat by desire to avoid changing any distinctive characteristics or quality of the product. In the more recently built plants some cost-saving improvements have been introduced to gain increased plant efficiency, but few changes were made in old plants until about 1944. The situation in the production of industrial alcohol usually has made it necessary to secure highest yields at lowest cost. Latitude in operation to achieve this end could be taken, since good distillation equipment usually produces a satisfactory industrial product regardless of the original material or process factors used. Changes in this industry were restricted by the prewar market situation and a hesitancy to increase investments. Only since the last years of the war have any considerable changes been adopted.

Since a continuous flow of product is desired, the ideal process should be based on a continuous flow or progression of the materials through the plant, rather than on a series of successive batch operations. Significant economies might thus be achieved. With such a process the entire plant might be reduced to the equivalent of a continuous pipe line in which the successive changes would be wrought on the raw and semiprocessed material while in continuous flow. Since about 1944 several significant improvements leading in this direction have been adopted commercially. These originated in the beverage-alcohol industry, since grain was involved, so that it was more particularly a problem of that industry. One of these improvements is the continuous cooking method, in which a premixed slurry of milled grain is continuously cooked by a steam jet, the cooked material continuously cooled, and malt continuously added to the moving material. The conversion of starch to sugar is completed in the fermenter. This method avoids hold-up of flow occasioned by use of batch-cooking equipment, and reduces the requirements for cooking equipment significantly. It has been adopted to a considerable extent in both the beverage and the industrial-alcohol industries because of simplicity of operation, saving of time, labor requirements, and equipment outlay. The method for continuous development of yeast also has been partly successful. Since the grinding of grain always has been done in continuous flow, it seems that alcohol production now can be made a continuous operation through all process stages up to actual fermentation.

Although there has been considerable experimentation on continuous fermentation, certain difficulties have precluded successful operation thus far, but it is conceivable that this problem may be solved. Since the subsequent alcohol-distillation and stillage-recovery steps already are continuous-flow processes, the successful operation of the continuous-fermentation step might permit the entire process to attain the pipe-line ideal previously mentioned. The future fermentation



alcohol processing plant, therefore, might be reduced to relatively smaller space, simpler equipment, and lower capital requirements.

The starch-conversion step in processing grain to alcohol is of great importance and has been studied extensively during the past few years. Much information has been developed on the action of enzyme systems on starch, but a great amount of fundamental information still is needed. Under present conversion methods, from 10 to 15 percent of the starch or other carbohydrate escapes conversion to alcohol and such losses have significant cost importance. A certain amount of the lost carbohydrate goes to yeast cell or glycerol production, and can hardly be avoided, but principally the loss represents unfermented starch. Since this usually is recovered subsequently as stock feed, actually the significance depends upon the relative value of feed or alcohol.

Theoretically, the change of starch to alcohol involves two distinct phases; first, a conversion (saccharification or hydrolysis) of the starch to fermentable sugars by enzyme action and second, a change of fermentable sugars to alcohol by action of living yeast cells. Yeasts can convert simple (6-carbon) sugars and certain more complex disaccharides (12-carbon sugars) such as maltose and sucrose to ethanol and carbon dioxide, with great rapidity. However, yeast cannot utilize starch or dextrans, hence the necessity of first splitting the starch molecule to smaller units (fermentable sugars) by suitable procedures. Commercially this usually is accomplished by malt (principally barley malt) which contains enzymes of the type required. Rye and wheat malts are used on occasion. Hydrolysis of starch by chemical action is possible, but because of certain disadvantages it has not been used commercially in grain alcohol fermentation. Since difficulties arise from present hydrolysis procedures employing enzymes, the alcohol fermentation theoretically might be improved, but the whole problem is extremely complex and progress toward solution is likely to be slow. Some of the complicating factors, as well as means suggested for solving the associated problems, are worthy of discussion.

The starch in grain, potatoes, etc., is not of uniform chemical structure but consists of a mixture of two types of molecules: (a) an *amylose* type in which the small glucose polymers or units which make up the large starch molecule are interconnected in a linear (straight chain) arrangement, and (b) an *amylopectin* type, in which the molecules are in a branched arrangement (main chain with branching side chains). The distribution in grain starch (exclusive of "waxy" grains) ordinarily is about 27 percent amylose and 73 percent amylopectin. The amylolytic (starch-splitting) enzyme system of malt also is a complex of at least two enzymes, *alpha*- and *beta*-amylase, each of which has a somewhat specific but differing action on the two types of starch. However, the enzymes usually are present in malt in quantities that are mathematically out of proportion for the starch constituents, if considered from a fermentable sugar-producing basis. It is not possible to determine accurately the actual enzyme percentages present in a malt, nor is the mechanism of action completely understood. The processor is confronted, therefore, with the problem of employing the enzyme-complex (malt) source in such a manner that the most economical operations are attained, the quantities of malt employed usually being limited, because of cost, to 8 to 10

percent by weight of the total grain used. Such quantities may be inadequate under certain conditions, or they may represent an undesired excess of *beta* and a shortage of *alpha* enzyme for the requirements for converting a particular starch mixture to simple sugars.

Enzyme degradation of starch to simple sugars may be considered as a series of reactions, each producing progressively smaller carbohydrate units. The intermediate products of partial hydrolysis of starch are known as dextrins. Dextrins, like starch, are not fermentable by yeast, and consequently the success of malt conversion becomes in part a problem of minimizing the amount of residual dextrins formed by inducing the greatest possible hydrolysis to sugar. Some dextrins are easily hydrolyzed to sugar, but other types are hydrolyzed at a very slow rate, if at all, during the fermentation process. Thus at this later stage the rate of fermentation is slow in comparison with the earlier rate of fermentation of the main sugar supply. While this secondary dextrin hydrolysis probably is accomplished principally by certain agents in the malt enzyme complex, an associated action of yeast enzymes may be involved.

Malting is a process of controlled germination of grain, in the course of which some natural enzyme systems of the original grain are increased. Only certain varieties of barley or other grain are economically suitable for the malting operation. The diastatic enzyme system of barley malt consists principally of (dextrinizing) *alpha*- and (saccharifying) *beta*-amylase. The quantities of each present will vary in amount, and in respective percentage, for different lots or varieties of grain. In addition, malt contains traces of other enzymes, the functions of which are not fully understood. Practically all of the *alpha*-amylase present is produced during the malting process, but its concentration varies, and frequently may be insufficient for maximum rates of starch hydrolysis and fermentation at the low percentage of malt used in the alcohol process. The *beta*-amylase is a natural constituent of ungerminated (barley) grain and its concentration is increased during malting, but to a lesser degree than that of *alpha*-amylase.

The two enzymes (amylases) seem to have different, but overlapping, functions. Stated rather generally, *alpha*-amylase seemingly can attack the branched chain (amylopectin) starch fraction, principally forming dextrins (so-called *alpha* dextrins of short chain, six to eight glucose molecules in length). However, it also can break down these *alpha* dextrins to sugars to some extent by subsequent attack. But in general it produces dextrins. *Beta*-amylase can break these *alpha* dextrins largely to fermentable sugar (maltose), and also can attack the linear starch (amylose) fraction to produce sugar (glucose). It also can attack the branched-chain starch (amylopectin) to some extent, seemingly producing *alpha* dextrins from the branches attacked. Its action is stopped, however, by the more complex conformations of the main chain and, in part, some more complex (*beta* or limit) dextrins are produced. Since all these actions occur more or less simultaneously with the reactions from other enzymes present, the results are difficult to assess or predict. While the *alpha* dextrins eventually are more or less converted to sugar and utilized, the *beta* or more complex dextrins may remain largely unutilized. Since the molecules in starch are predominately amylo-

pectin (or branched chain), it might be considered that the relative amounts of *alpha*- and *beta*-amylase normally existing in malt are out of proportion to the types of starch present, considering possible action thereon. Laboratory studies by the Bureau of Plant Industry, Soils and Agricultural Engineering have shown that certain increases in starch conversion and alcohol formation can be gained by increasing *alpha* activities of malt, up to a certain level, above which no great influence of the increased *alpha*-amylase is evident. Other enzyme systems may be involved. However, it has been found recently that the addition of additional *alpha*-amylase, obtained from sources other than malt, to a malt conversion mash, achieves a reasonably rapid hydrolysis of the starch, particularly representing a saving on the equipment/time factor. A slightly improved dextrin utilization ordinarily is attained.

In usual alcohol plant practice, grain mash is saccharified in three successive operations. In the first, a small amount of malt, usually in amounts approximating 1 percent by weight of the total grain bill (equivalent to about 10 percent of the total malt used) is added to the grain and water mixture (slurry) to preliquefy the mash. This step frequently is referred to as premalting. It is important because, during cooking (particularly when working at high grain concentrations, a practice commonly employed to economize steam) in batch processing, the grain mashes become so viscous that mixing and pumping operations are extremely difficult. Preliquefaction accomplishes sufficient degradation of the starch so that, upon gelatinization, proper flow or handling characteristics are obtained. Preliquefaction is principally a dextrinization reaction accomplished by the *alpha*-amylase.

The second saccharifying operation starts when the viscosity of the mash slurry is reduced sufficiently. This consists of thoroughly cooking the slurry to gelatinize the starch. Generally, cooking is accomplished at high steam pressure, although cooking at atmospheric pressures is practiced in some older plants. Gelatinization alters the starch structure sufficiently to permit more rapid and complete (subsequent) enzyme hydrolysis. After the cooking operation and reduction of temperature to about 145° F., as a third stage, the bulk of the malt is added to accomplish the main saccharification, which proceeds rapidly at first. After a short holding period (8 to 30 minutes) the mash is cooled to about 78° F., transferred to the fermenter, and inoculated with the yeast (procedures vary). Yeast action develops rapidly and a vigorous fermentation (of sugar) ensues. Later, as the available sugar becomes largely metabolized into alcohol by the yeast, the fermentation rate decreases and the relatively slow and incomplete degradation of the dextrins (into sugar) by the enzymes present then becomes the limiting factor. During this more sluggish stage of fermentation certain contaminating acid-forming bacteria that unavoidably are present in the mash have an opportunity to multiply and to utilize sugar in competition with the yeast. The titratable acidity gradually increases and the pH drops, which further hinders the dextrin splitting enzyme activity and, in turn, limits alcohol formation by the yeast. A point soon is reached where the fermentation becomes "dead," and any unconverted dextrins remain unutilized.



In attempting to overcome such factors that impair the full utilization of the starch in grain, research workers have turned to other sources of amylolytic enzymes which might be used to supplement or replace malt. The most desirable method would result from use of enzymes capable of rapid and complete starch and dextrin conversion direct to simple sugars, without the formation of residual dextrans, if these can be found. Certain micro-organisms offer potentialities as sources of enzyme systems of applicable type.

Certain molds and bacteria produce starch-hydrolyzing enzymes, including an *alpha*-amylase and "maltase," *beta*-amylase, however, usually being absent. This source of amylolytic enzymes from the molds is now being studied extensively. Evidence is accumulating that the enzyme maltase plays an important role in production of fermentable sugar (12, 17). It appears that this enzyme system may be capable either of hydrolyzing starch directly to glucose or of degrading dextrin to glucose very rapidly. Thus, the end product of mold enzymes on starch differs somewhat from that achieved by malt action, glucose rather than maltose essentially being produced. Since both of these sugars yield alcohol in equivalent amounts, this may not be significant. The actual value of the mold enzyme may depend on its ability to attack dextrans.

There is evidence that the *alpha*-amylases produced by various micro-organisms may not be exactly identical, and these *alpha*-type enzymes may differ functionally from malt *alpha*-amylases. The total variation in malt-enzyme systems, by barley varieties, is relatively smaller than the range of possibilities of *alpha*-amylase and maltase ratios offered by the many microbial species. Therefore, eventually, it may be possible to isolate individual species of micro-organisms which might yield the necessary enzymes in correct proportions for any saccharifying problem, or perhaps the action of several species might be combined to attain the desired results. A start has already been made by the discovery that the amylolytic enzyme complex from certain micro-organisms may completely replace malt in the saccharifying process without lowering present alcohol yields. Ordinarily, this substitution can represent a saving in cost.

The use of microbial amylases for certain dextrinization and saccharification operations is not new, but their application to the alcohol fermentation has been revived only recently. Some commercial processes have been evolved for producing microbial enzyme preparations for certain industrial uses. These processes principally utilize varieties of molds such as members of the genera *Aspergillus*, *Rhizopus*, and *Mucor*, and bacteria of the *Bacillus* group. Molds have been used by Oriental peoples from time immemorial for the conversion of starch into food and beverage products. The art is now being studied to establish a more scientific basis for the process.

Three different procedures that employ fungal (mold) amylases have been utilized with alcohol fermentation. The oldest of these is the "amylo" process, developed from the Oriental starch conversion methods by Calmette, and employed in France as early as 1892-94. *Amylomyces* (*Mucor*) *rouxii* was cultured aerobically in the cooked grain mash until saccharification was accomplished, yeast being added subsequently to ferment the sugars to alcohol. Later, other molds were substituted. This process never attained widespread interest in

the United States because of undesirable features, principally the long time required for processing and the serious bacterial contamination frequently encountered during the development of the mold amylase, which lowered the alcohol yields appreciably. Recently, the process has been revived for wheat fermentation in Australia (23) at the Cowra distillery, according to reports.

Two alternative procedures of using fungal amylase have been developed, both of which overcome the serious objection to the amylo process by producing the amylolytic preparation prior to its incorporation in the grain mash (thereby being analogous to the use of malt). The first, investigated in the United States as early as 1891 by Takamine, has been revived recently as the "mold-bran process," in which *Aspergillus oryzae* is cultured on moist wheat bran until maximum amylolytic power is attained, after which the product is dried and handled much the same as malt. This product contains amylolytic enzymes (principally *alpha*) in greater concentration than malt. In alcohol production this material can be used to supplement or replace a large part of the malt, alcohol yield remaining at least as large while less original enzyme material is required. Thus a more economical saccharification may result if the bran is not too expensive. However, this process of producing mold enzyme has at least one disadvantage. The low heat-transfer properties of bran make sterilization difficult, so that bacterial contamination may occur, with consequent loss in yields of desirable enzymes. Bacterial contamination is also a disadvantage in using malt.

Another procedure, promising perhaps greater economies, has been developed recently at the Northern Regional Research Laboratory, wherein fungi such as *Aspergillus niger*, *A. oryzae*, or certain strains of the genus *Rhizopus* are cultured aerobically under submerged conditions in thin stillage from the alcohol plant, supplemented with a small amount of corn meal and certain chemicals (17). This liquid amylase preparation may be used to supplement malt, and it has been demonstrated that it may replace malt completely without sacrificing alcohol yields. However, yields are not significantly increased, nor are operating procedures improved greatly. But, since the thin stillage is returned to the alcohol process in the subsequent fermentation cycle, the material cost of such enzyme production is limited to the small amount of chemicals utilized. Inactive plant equipment presumably might be used for preparation of the enzyme. The disadvantages encountered in the use of mold bran are obviated because sterilization is more easily accomplished and handling is reduced to a minimum. Thus the inherent economies and the theoretical simplicity of the process indicate attractive potential possibilities. The comparable employment of dry distillers' solubles, in lieu of original thin stillage in this process has been advocated also. Preparation of enzyme material at an alcohol plant, of course, increases plant and personnel requirements correspondingly. Malt ordinarily is purchased (from malsters) by distillers.

A procedure whereby the naturally occurring starch saccharifying enzymes of wheat can be used to partly replace malt in wheat alcohol fermentations was proposed in 1944 and patented in 1948 by Tucker and Balls (25). This process is based on liberating the natural enzymes in the wheat by treatment of the uncooked grain mash with

sulfites. Inherent difficulties, principally as the result of the widely variable amylase content of wheat, have limited commercial application thus far.

It has been claimed that some of the alcohol losses now sustained by failure to ferment dextrins to alcohol, are owing in part to formation of retrograded products from starch in the cooking operation. Presumably the retrogradation occurs after gelatinization, and before the addition of saccharifying enzymes. It is claimed that quick cooling of the gelatinized mash through the temperature range of 180°-140° F. can avoid this retroaction. This possibility is now being investigated.

Refermentation of stillage by fungal agents to increase amino acid and/or vitamin values in the byproduct feed, might offer a means of reducing over-all alcohol costs by increasing the value of byproducts. Also, some attempts have been made to referment stillage to recover alcohol from the unfermented pentose sugars present in the residual grains or in the processing wastes.

Attempts have been made to reuse the yeast for successive fermentations. Since the yeast cells are propagated at the expense of carbohydrate, such reuse should increase alcohol yields by an equivalent degree. In grain and molasses fermentation plants in this country the yeast is not reused ordinarily. In the reuse process, the yeast is allowed to settle out (as in brewery processing) or is centrifuged from the fermented beer. In the case of whole-grain mashes, the yeast separated from the beer will be contaminated by the unfermented grain residue and the reuse becomes relatively impractical. With molasses or granular wheat flour, however, a relatively clear beer is handled and yeast separation becomes relatively simple. Chief hazards of reuse lie in the difficulties of preventing bacterial contamination and in maintaining good viability in the yeast cells. Failure at either of these points would entail lowered alcohol yields. The process currently is being employed commercially in the production of alcohol from waste sulfite liquor and it has been proposed for the fermentation of molasses, several plants in Cuba having experimented thereon. Significant increases of alcohol yield are claimed. The process permits the use of a higher concentration of yeast cells in the mash, thus inducing a more rapid rate of fermentation, and it is particularly desirable with solutions of low-sugar concentration. If high-yeast concentration were achieved by actual growth of the cells in such dilute solutions, then the carbohydrate might all be expended on yeast growth with little yield of alcohol.

#### BYPRODUCTS AND THEIR VALUE

The principal chemical byproducts from the fermentation of carbohydrates to alcohol are carbon dioxide and fusel oil, which may be recovered during the fermentation and distillation steps, respectively. When corn is employed as the carbohydrate source, corn oil may be recovered by preseparation and treatment of the corn germ. After fermentation and distillation of grain mashes, byproduct feed (distillers' grains) also may be recovered from the waste stillage; since only the starch is removed, the proteins and minerals originally present in the grain remain relatively unattacked. In addition, vitamin values of the stillage are higher than those of the original grain, while protein



from the yeast cells also is recoverable. Stillage is high in water-soluble vitamin content and, in the case of corn stillage, some carotens, precursor of vitamin A, is present.

#### STILLAGE

Much development has been achieved in the past few years on recovery of stillage. Obtaining greater returns from the unfermented material present in these often wasted residues decreases the manufacturing cost of the alcohol, particularly in grain-using plants. In the prewar period, the possible recovery of values from the stillage usually was not wholly exploited (8), this being true especially in the industrial-alcohol industry. So far as known, only one molasses alcohol company has consistently made recovery of stillage, and this perhaps was undertaken primarily as an effluent disposal measure to avoid stream pollution, since the recovery expense at times may have exceeded the returns. With the high molasses prices existing in 1947-48, some occasional recovery may have been made elsewhere to produce a molasses substitute, suitable for incorporation with livestock feeds.

The distilled-spirits industry, however, made considerable prewar recovery of grain residues as feed, either by direct feeding of stillage to cattle or hogs, or by screening the solids from the stillage and drying them for sale, in most instances without further recovery of the filtrate (or "thin" stillage). Recovery of this thin or dilute material presented a complete evaporation problem and was not considered economic at most of the older and smaller plants, consequently much of it was dumped into streams. Only a few plants operated for complete stillage recovery, the thin stillage ordinarily being evaporated to a sirup and added to the screenings for final drying. Thin stillage (distillers' solubles) was first produced by one company in separate, dried form, about 1939. The modern distilleries and industrial alcohol plants, using grain, that have been built in recent years are designed for complete stillage recovery, although even in these plants it frequently has been commercially impracticable to recover 100 percent of the waste material. Since 1944, shortages of feed materials have stimulated efforts toward more complete recovery of distillation residues and now many plants are fully equipped to accomplish this. With the growing realization of the value of the vitamins as well as that of the proteins in the stillage, and with increasing specialized use of distillers' grains in feeding, there has come an increase in the quantity, quality, and diversity of byproduct materials marketed. Recently the trend has been to use only a portion of the total thin stillage for coating screenings to make dark grains, the remainder of the solubles being dried separately. Cost of such drying is higher than the cost of coating the screenings and drying. Therefore, relative market values of the solubles (usually \$10 to \$20 per ton higher than dark grains) are a large factor in determining the actual recovery method employed.

Considerable latitude exists as to method or form of use of the unfermented residual portions of the grain as feed, and potential markets may exist for practically any amount now producible. The material can be fed to animals direct as whole stillage or it can be recovered in fractions of different composition, which can be fed direct, or dried

and shipped. Dried commercial products <sup>23</sup> now include:

*Distillers' Dried Grains (so-called light grains).*—This product consists of the solids ordinarily removed from the stillage by simple screening and dried separately.

*Distillers' Dried Grains With Solubles.*—This product represents a more nearly complete recovery of the stillage, effected in two stages; the screenings (light grains) are coated with the major part or all of the sirup obtained by subsequent evaporation of the liquid that passes through the screens (thin stillage) and dried further, or the two portions (screenings and sirup) are mixed after being dried separately. Products of either method are known as dark grains.

*Semisolid Distillers' Grains with Solubles.*—This product is the whole stillage (unscreened) evaporated to a sirupy consistency.

*Semisolid Distillers' Solubles.*—This product is obtained by evaporation of the thin stillage (only) to a sirup.

*Dried Distillers' Solubles.*—This product is obtained by evaporating and drying the sirup from the thin stillage, by drum or spray dryers. It contains no screenings.

Each of the foregoing classifications is further identified by the principal raw material origin, as corn, wheat, rye, molasses, etc. In addition, there have been efforts toward production of:

*High Vitamin Concentrates.*—Products obtained by special recovery methods, or by reinoculation and refermentation of stillage.

*Special Protein Fractions.*—Products obtained by protein precipitation methods.

The last two types mentioned represent a new trend in the industry toward the development of specialized products. Potential profits in this field might exceed the profits from alcohol production and exert a marked effect on alcohol-production costs. At present, equipment has been installed in most grain-fermentation plants to the extent that approximately all the potential feed available from all the grain which they now may ferment can be recovered, mainly in dry form, although some of the smaller plants still may resort to the old method of direct feeding of wet stillage, as a side line, or sale of thin stillage to local stock feeders.

Production of distillers' dried grains (1,000-ton units) has been reported (33) as shown in table 13.

TABLE 13.—*Production of distillers' dried grains*

[In units of 1,000 tons]

Year (Oct. to Sept.)	Light grains	Dark grains	Dried solubles	Total
1942-43 .....	( <sup>1</sup> )	( <sup>1</sup> )	( <sup>1</sup> )	356.9
1943-44 .....	285.4	131.2	27.3	443.9
1944-45 .....	352.6	195.4	85.5	633.5
1945-46 .....	133.4	88.6	105.9	327.9
1946-47 .....	157.4	148.7	105.2	411.3
1947-48 .....	130.1	147.8	73.2	351.1

<sup>1</sup> Not itemized.

<sup>23</sup> Authorized by the Association of American Feed Control Officials, Inc. (1944), and usually so identified in State laws.

Previous to 1942, total production ran as low as 149,100 tons in 1938-39. Average ton prices, all grades, in bags (Cincinnati) have varied from \$19 per ton (April 1936) to \$94 (January 1948). Previous to the war the general fluctuation was in the \$25 to \$34 range.

These distillers' residues are useful in adjusting the protein values of mixed feeds. For certain types of feeding, whole grain may contain an excess of carbohydrate over the proportionate protein needed for balanced nutrition. Therefore, in feeding practice, grain frequently is supplemented by a material of high protein content whereby original ratios of high carbohydrate to low protein are adjusted to suit the needs. About 16 to 18 pounds of byproduct feed with a protein content of 25 percent or more are obtained from a bushel of corn where plant operation is efficient. Protein content of the dried soluble fraction may reach 45 percent. These residues also contain amino acids, vitamins, etc., resulting from the yeast action. These byproduct grains have a basic nutritional value, but their actual effect when used in mixed feeds will depend upon the type of feeding and the basic mixture.<sup>24</sup> Essentially they compete with cottonseed meal, soybean meal, dried skim milk, and similar byproduct agricultural materials used for feeding.

Experimentation has been made on refermentation of the stillage to increase vitamin content, particularly that of vitamin B<sub>2</sub> (or riboflavin), and some commercial production has been achieved. Protein values also might be increased by refermentation with yeasts, in which case additional nitrogen would have to be supplied to the mash. The stillage might also serve as raw material for the production of bacteriological products. Additional developments in this field may be anticipated. Some vitamin values established by Bauernfeind (6) are shown in table 14.

<sup>24</sup> Claims that "distillers do not remove any nutrient from grain," (in alcohol production) are not essentially true, as sometimes worded. Since starch is a nutrient, its removal means the loss of perhaps two-thirds of the total nutritive value of the grain. Viewed from certain nutritional aspects, however, such starch often may not be as essential or desirable as the residual protein, the percentage of which is increased by the removal of the starch. Thus the remaining third of the original total nutritive value may have, therefore, an enhanced value as a supplement to other feed, under certain conditions.



TABLE 14.—*Vitamin composition of alcohol fermentation byproducts from various grains*<sup>1</sup>

Byproduct	Cooking temperature <sup>2</sup>		Proximate composition (dry-matter basis)				Vitamin content (dry-matter basis)			
	° C.	° F.	Protein	Fat	Ash	Fiber	Thiamine	Riboflavin	Nicotinic acid	Pantothenic acid
Wheat distillers' dried solubles	68.3	155	Percent 46.5	Percent 0.5	Percent 8.8	Percent 2.2	μg./g. 10.0	μg./g. 15.2	μg./g. 210.0	μg./g. 44.0
	100.0	212	39.0	.8	10.1	2.5	4.5	13.6	232.0	44.0
	137.8	280	37.0	.9	10.0	2.4	4.5	14.0	228.0	46.5
	155.6	312	35.8	.6	10.1	2.3	4.2	14.1	220.0	45.0
Wheat distillers' dried grains	68.3	155	27.2	5.5	2.3	14.7	---	4.1	72.0	7.8
	100.0	212	37.9	4.7	2.8	12.0	1.8	3.3	86.0	7.4
	137.8	280	39.5	4.3	2.5	13.1	1.8	3.7	82.0	7.0
	155.6	312	42.6	---	2.1	13.9	1.3	2.9	74.0	6.3
Corn distillers' dried solubles	100.0	212	21.7	5.2	9.7	3.8	11.0	17.8	172.0	25.0
	137.8	280	28.5	6.6	9.5	3.8	6.5	15.1	141.0	25.5
	155.6	312	24.7	---	9.3	3.1	7.9	18.6	162.0	22.0
	100.0	212	30.5	10.3	1.9	12.1	2.2	3.5	47.0	4.4
Corn distillers' dried grains	137.8	280	32.3	10.3	2.0	12.8	1.5	3.3	31.0	5.0
	155.6	312	33.9	11.4	1.8	13.2	1.5	4.0	43.0	3.9
	68.3	155	40.4	.7	8.0	2.6	4.0	13.2	45.0	33.0
	137.8	280	36.4	.7	8.5	2.8	3.5	14.0	52.0	35.0
Rye distillers' dried solubles	68.3	155	24.0	6.3	2.2	13.0	1.9	3.6	18.0	7.0
	137.8	280	28.9	6.8	2.3	13.4	1.6	3.8	19.0	5.5
	155.6	312	46.0	1.1	5.3	2.2	5.3	11.5	81.0	23.7
	137.8	280	42.8	1.3	4.9	2.9	6.0	10.9	80.0	24.3
Granular wheat flour distillers' dried solubles	68.3	155	27.0	4.5	2.6	15.7	2.6	3.4	42.5	5.9
	137.8	280	44.0	3.2	2.4	11.2	2.2	4.5	46.8	4.4
	155.6	312	---	---	---	---	---	---	---	---
	137.8	280	---	---	---	---	---	---	---	---

<sup>1</sup> Source: Bauernfeind, et al. (6).<sup>2</sup> Refers to maximum temperature reached in the cooking cycle.

## CARBON DIOXIDE

Carbon dioxide recovery represents a potential source of income to the alcohol plant, within the limits of possible markets. About a pound of carbon dioxide is released during fermentation for each pound of alcohol produced. However, under existing plant methods only part (perhaps 70 percent) of this gas may be economically recoverable. Furthermore, market situations in the past have tended to limit annual over-all commercial recovery to perhaps 40 percent of the original gas produced, because of seasonal fluctuations in demand. Since solid carbon dioxide vaporizes rapidly and is lost, the time of storage is limited. Thus it has been relatively impractical to store reserves for the period of heavy demand in midsummer. Recently, by use of specially constructed holders, storage for relatively long periods seems to be more feasible. Liquefied gas stored in cylinders is free from evaporation loss but storage is limited by the relatively high expense represented by the cylinders.

The raw gas must be purified. Distillery gas must compete with carbon dioxide from stack gases, natural dioxide gas wells, and other sources, as well as with mechanical and ice refrigeration. The over-all returns from carbon dioxide recovery are not likely to exceed a credit of 4.7 cents per gallon for limited operation periods, and the yearly average is unlikely to net more than 2 cents per gallon of the alcohol produced, as possible maximums. In actual experience the credit value of carbon dioxide recovered at alcohol plants has averaged much less. The markets for carbon dioxide in 1944 assimilated 226,370,000 pounds in liquid form and 666,009,000 pounds in solid form. Both liquid carbon dioxide (compressed in cylinders) and solid carbon dioxide (dry ice) constitute specialty products. One large apparent market in which further development possibly might occur is the use of solid carbon dioxide in refrigerator cars in transit.

Accurate information on the total production of fermentation carbon dioxide in the United States is lacking, and the extent of the potential market cannot be stated accurately. About 15 alcohol plants now are equipped to recover carbon dioxide, the majority selling the gas to a subsidiary for purification and distribution. Toward the end of World War II this production may have amounted to about 22 percent of the market requirements, as estimated from installation capacities.

## FUSEL OIL

Fusel oil is a variable mixture of higher alcohols, principally isoamyl and d-amyl, with some normal, isobutyl, and propyl alcohols and corresponding esters. It occurs in amounts approximating 1 to 5 gallons per 1,000 gallons of alcohol produced. The actual amounts depend on the raw material used, the conditions of fermentation, and the operation of the alcohol rectifying equipment.

Fusel oil originates principally from decomposition of proteins or amino acids by yeast action, although some of the propyl or butyl constituents may result from carbohydrate decomposition. For example, iso-amyl alcohol seems to be derived from leucine, and d-amyl alcohol from iso-leucine (14, pp. 168-170).

Fusel oil has long been used as a solvent for nitrated cotton, and as a source of amyl compounds. Recently it has found use in the

recovery of crude pencillin. The oil is recovered at most industrial alcohol plants and in distilleries of modern design, but not at many of the smaller, older distilleries. Production in 1945 was 11,400,000 pounds (crude and refined). Amyl alcohol (normal) is now made synthetically from pentane gas (from petroleum), and also may be a byproduct of Fischer-Tropsch reactions. Synthetic production may present strong competition to the fermentation product. There are eight isomeric forms of amyl alcohol, about five of which appear commercially. Most of these originate from synthesis operations.

#### CORN OIL

Corn oil may be recovered from corn germs removed from the grain before fermentation. Most of the oil present in the kernel is in the germ, about 5.5 pounds of germs being recoverable per bushel of corn. Only one or two alcohol (beverage) plants degerminated corn and/or recovered corn oil in 1943. Most of the corn oil now produced commercially is a byproduct of the cornstarch industry. About 1.5 to 1.7 pounds of oil is obtained from a bushel of corn by the usual wet-milling process. Oil yields from dry milling (ordinary grinding and germ separation) are considerably less (about 0.6 pound), since only a portion of the germ can be separated easily from the milled grain. Alcohol plants ordinarily use dry-milling methods only. Degermination or oil extraction of grains used in distilling, other than corn, is not practiced. Removal of the corn germ before fermentation should not reduce alcohol yields (per unit of original grain) significantly, since the press cake from the oil removal operation subsequently can be returned to the fermentation mash for utilization of incidental starch, the remainder being recovered as distillers' grains. Corn-oil extraction eventually might be practiced more generally by distillers, but the market situation seemingly will be dominated by the far larger production of corn oil by the cornstarch industry.

#### FEED YEAST

The production of yeast for feeding purposes, as an adjunct of alcohol operations, might produce additional income. If high alcohol yields from a given amount of carbohydrate are desired, yeast growth must be minimized. Conversely, if luxuriant yeast growth is desired, alcohol yields are sacrificed. Yeast for food purposes is now produced in special plants mainly utilizing cane and beet molasses, and alcohol yields are minimal, growth of yeast cells being stimulated by supplying additional oxygen. Such growth is based on use of 6-carbon sugars; however, special types of yeast (*Torulopsis utilis*) suitable for feed can be grown on the 5-carbon sugars (pentoses) present in some fermentation liquors. This is now being done abroad in conjunction with the production of alcohol from wood and sulfite liquor, particularly. Approximately a half pound of yeast can be derived by use of a pound of sugar, and costs currently are estimated at 8 to 10 cents per pound, depending on the cost of the sugar employed.



## ALCOHOL MARKETS

During World War II, because of the extraordinary increase in alcohol requirements and inadequate supply, it became necessary to control distribution and use of alcohol as well as production. Allocations by the War Production Board (44) for the various uses of ethyl alcohol are shown in table 15.

Prewar uses of industrial alcohol are included principally in the last two allocation items of this table, most of the remainder constituting war requirements. Increases in civilian use above the prewar normal also are owing essentially to war demands. However, the situation represents enlarged usual markets rather than significant new uses or market outlets for alcohol. An exception is in the production of synthetic rubber, a field of use which represents a new and highly significant market outlet that absorbed alcohol at a rate of about 330 million gallons annually at its peak. This quantity represents approximately 300 percent of the total prewar annual consumption of alcohol for general industrial uses, and half of the annual war production of alcohol.

The item of "indirect military and civilian" uses in table 15 represents essential general manufacturing. Distribution to the various uses was estimated (45) as follows:

TABLE 15.—*Allocations of alcohol (190-proof) for usage during World War I*<sup>1</sup>

Allocation	1940	1941	1942	1943	1944	1945 esti- mated	1945 actual Jan. 1 to June 30	Over-all allocations June 1, 1943 to June 30, 1945	
								Quantity	Percentage
Usage:									
Direct military	Million gallons	Million gallons	Million gallons	Million gallons	Million gallons	Million gallons	Million gallons	Million gallons	
Lend-lease	18	46	40	27	45	15.1	82.2	6.2	
Synthetic rubber	9	25	63	57	60	23.0	142.9	10.9	
Antifreeze	19	30	126	330	349	154.7	611.2	46.4	
Indirect military and civilian	122	23	128	51	36	9.5	92.1	7.0	
Total	141	165	229	148	160	80.9	389.1	29.5	
Supply:									
Total domestic production	137	215	229	428	606	655	283.2	1,317.5	100.0
Total importation		217	297	437	568	668			
Government stocks at end of year			1	12	33	35			
			64	87	81	29			

<sup>1</sup> See: (44, p. 128).

## ALCOHOL USES IN 1944

		<i>Million gallons</i>
<b>Industrial uses:</b>		
Chemical solvents	-----	42. 0
Tetraethyl lead	-----	25. 2
Rayon and plastics	-----	20. 4
Solvents and thinners for liquid coatings	-----	15. 0
Cellulose resins, etc	-----	12. 0
Industrial processing	-----	9. 0
Miscellaneous	-----	4. 4
Subtotal	-----	128. 0
<b>Consumer uses:</b>		
Vinegar	-----	10. 0
Proprietaries	-----	6. 0
Food and medicinals (internal)	-----	3. 0
Fluid (experimental and fuel)	-----	. 9
Government (excluding military)	-----	2. 4
Hospitals and science (excluding Government)	-----	1. 2
Miscellaneous	-----	. 9
Total	-----	24. 4
The distribution may be summarized as follows:		<i>Percent</i>
Protective coatings	-----	24. 4
Plastics	-----	12. 8
Textiles	-----	12. 6
Tetraethyl lead	-----	11. 8
Public health	-----	7. 5
Food	-----	4. 6
Explosives (private production)	-----	3. 6
Miscellaneous (exclusive of rubber and antifreeze)	-----	22. 7

Of these uses, the tetraethyl lead ("gasoline antiknock") item deserves further consideration because of its future potentialities. The antiknock compound now used in motor fuel contains tetraethyl lead, and the alcohol allocated for gasoline-antiknock use was intended principally for manufacture of this compound. However, alcohol itself can be used as a straight fuel for internal-combustion engines, or as an ingredient of fuel blends to obtain increased antiknock or other desirable effects. This will be discussed later, as representing another new and significant market outlet for alcohol. Such use has been suggested in past years, but so far it has failed to achieve success in this country. Use of any large quantities of alcohol for this purpose during periods of inadequate supply would be impracticable.

The annual consumption of alcohol (completely denatured) as an antifreeze agent now may amount to about 29 million gallons or perhaps less, since methanol and certain high-boiling materials (glycerine and ethylene glycol) are also used extensively. The lack of these other materials during wartime, however, necessitated the allocation of 50 million gallons of alcohol for such use in 1943. There are some other uses for completely denatured alcohol (varnish thinner, canned heat, crude solvent, etc.), but production of alcohol in this form is decreasing (see table 1).

The greatest industrial use of alcohol is in specially denatured forms, of which 57 different formulas are authorized at present (30). Use of alcohol in this form is limited by a permit system, since in some instances purified alcohol might be illegally recoverable from it, to avoid payment of tax. Uses of specially denatured alcohol are shown in table 16.



TABLE 16.—*Uses of specially denatured alcohol*

General field of application	Specially denatured alcohol <sup>1</sup> used in—					
	1930 <sup>2</sup>	1936	1942	1946	1947	1948
	<i>Million gallons</i>	<i>Million gallons</i>	<i>Million gallons</i>	<i>Million gallons</i>	<i>Million gallons</i>	<i>Million gallons</i>
Lacquers, varnishes, and enamels	17.7	9.3	7.7	4.4	4.4	3.8
Plastics	6.4	5.4	4.8	3.5	3.8	3.8
Film, explosives, adhesives	14.0	2.4	<sup>3</sup> 28.1	1.8	9	8
Solvents, thinners	1.0	10.5	24.5	18.3	21.4	18.3
Processing industrial food and drug products	10.5	27.1	<sup>4</sup> 9.4	11.1	12.2	10.8
Toilet preparations	7.7	3.3	5.6	7.4	6.0	5.1
Pharmaceuticals (external)	2.0	3.4	3.6	3.0	2.8	2.9
Cleaning, preserving, flavorings	3.0	1.9	2.8	1.4	1.3	1.4
Vinegar, acetic acid, and ethyl acetate	16.7	12.7	18.1	14.0	18.0	9.8
Converted in chemical manufacturing	( <sup>5</sup> )	15.8	22.2	<sup>6</sup> 90.5	<sup>6</sup> 19.3	<sup>6</sup> 19.1
Acetaldehyde		16.6	34.4	54.0	65.5	72.9
Miscellaneous	5.8	.6	8.0	1.0	1.0	1.2
Total	84.8	109.1	169.2	196.4	157.1	149.8

<sup>1</sup> Figures represent only new alcohol used (exclusive of recovered alcohol) but include alcohol recovered and not reused in current year. Recovered alcohol runs about 128 million gallons annually. Source: Alcohol Tax Unit.

<sup>2</sup> Estimated. Statistics not reported on same basis in successive years.

<sup>3</sup> Explosives alone, 26.7 million gallons.

<sup>4</sup> 62.8 million gallons actually used; most of it recovered for reuse.

<sup>5</sup> Included in other items.

<sup>6</sup> Includes 62.67 million for synthetic rubber, 1946; 9.3 million, 1947; 0.37 million, 1948.

Table 16 shows that the largest industrial uses of alcohol are for the production of acetaldehyde, acetic acid and its esters, such as ethyl acetate, and for general solvent purposes. Acetic acid and its derivatives can be made synthetically from acetylene, and have been made thus for some years. However, the market requirements of such acetic derivatives previous to the war were partly filled from natural sources (wood distillation and acetic fermentations), although synthetic products constituted the major source. New plants are being built to make these chemicals synthetically from petroleum gases. Any future expansion of such direct production is likely to decrease the future requirements for ethyl alcohol.

#### COMPETITION FROM OTHER ALCOHOLS

Ethyl alcohol is meeting increasing competition from other alcohols, principally methyl, isopropyl, and butyl, for many purposes, such as antifreeze, solvent, chemical, cosmetic, and general use. Glycerine also can compete in certain fields.

Production of isopropyl alcohol has been increasing markedly. This chemical, under allocation during the war, has been manufactured synthetically for more than 20 years. From January 1, 1943, to June 30, 1945, the yearly consumption ranged between 66 and 89 million gallons. About 20 million gallons of this was used for purposes that might compete more or less directly with ethyl alcohol. Isopropyl alcohol is made from propylene gas occurring in the waste gases from petroleum refining, and can be made by sulfuric acid absorption in a manner analogous to the production of synthetic ethyl alcohol from ethylene derived from the same raw material source. Propylene is more readily absorbed by sulfuric acid than is ethylene and ordinarily it is more plentiful in the original gas source, hence competitive production may increase in the future. Acetone can be produced from isopropyl alcohol by dehydrogenation. Normal propyl alcohol is now available commercially also, produced by synthesis.

In 1947, because of shortages of methanol and ethanol, demand for isopropyl alcohol was greatly increased, and exceeded the 110 million gallons produced (2, p. 120). About 70 percent of the production was used for acetone manufacture, since fermentation acetone supply was somewhat curtailed by shortages of raw material for butanol production. About 10 percent was used for antifreeze. This illustrates how the present alcohol/solvent situation differs from the prewar status. All these alcohols now are interrelated in various fields of use, and users can turn from one chemical to the other when shortages or high prices affect any particular one. This consequently tends to keep market prices for the several alcohols in relative alinement, ordinarily.

Methanol is now made principally by pressure synthesis from a mixture of carbon monoxide and hydrogen. It also is a byproduct of

wood distillation. It can compete with ethyl alcohol as a solvent or as an antifreeze, but because of its inherently poisonous character,<sup>25</sup> its use is limited in certain fields. About 30 million gallons went into antifreeze in 1947. Production of natural (wood distillation) methanol runs about 5 million gallons per year, this being used principally for denaturing ethyl alcohol. Synthetic production increased from 44.6 million gallons in 1939 to 150 million in 1948, three new plants having come into operation recently. Principal specific use is as raw material for formaldehyde manufacture. Methanol can be made as an alternate product in synthetic ammonia (ordnance) plants.

Butyl alcohol is a less significant competitor of ethyl alcohol, since it differs more markedly in boiling temperature and solubility. However, it finds some competitive use as a solvent. The esters of butanol (and in fact those of all these lower carbon alcohols) can compete extensively with the esters of ethyl alcohol in many fields.

Certain physical constants of ethyl alcohol and related or competing organic compounds are shown in table 17. The data presented in this table represent values for products as commercially obtainable (technical grade), rather than for pure compounds. Acetates of the various alcohols, as listed, and acetone and methyl ethyl ketone are used principally for formulation of cellulose-ester lacquers or coating compounds. Ethylene glycol competes more directly with methanol and ethanol as an antifreeze agent. Methyl, ethyl, and propyl alcohols compete in the general solvent field. Such materials, however, do not compete in instances where the inherent chemical radicle is used for synthesis of new chemical compounds.

<sup>25</sup> Oxidation or metabolism of methanol in the human body essentially generates formaldehyde, formic acid, or ultimately carbon monoxide. All of these are toxic, hence there is *no* method by which methanol can be rendered nonpoisonous, if taken internally. Even simple inhalation of sufficient quantities of vapor from pure methanol can have serious effects in instances. Conversely, the oxidation products of ethyl alcohol ordinarily are acetaldehyde, acetic acid, and ultimately carbon dioxide, all of which (in *reasonable amounts*) are tolerated by, or eliminated with relative ease from the body. Products of methanol ordinarily are *NOT* tolerated to any extent, or eliminated as easily, hence there is a fundamental distinction between the two alcohols. Wood distillation (natural) methanol, as marketed many years ago, frequently contained traces of allyl alcohol or similar impurities, the vapor from which frequently irritated the mucous membranes of the eye. Such effect had no relation to the toxicity of methanol itself, but a popular misconception arose as to the cause of the trouble, and as to possibilities of purification. Some States have specific laws covering methanol use. However, the toxicity danger tends to be exaggerated. The author was engaged in natural methanol production for many years, but never saw an instance of methanol poisoning, identifiable as such, among the personnel of the various plants. Inflamed eyelids or mucous surfaces often were noted, following spillage of hot impure alcohol in plant accidents, but such effects apparently were temporary.



TABLE 17.—Physical constants of ethyl alcohol and related or competing organic compounds (commercial products)<sup>1</sup>

Substance	Molecular weight	Boiling point (pure substance)		Distillation range of commercial products	Specific gravity at 20/20° C.	Weight of gallon at 20° C.	Flash point (open cup)	Evaporation rate at 92° F.	Water solubility at 25° C. <sup>2</sup>
		° C.	° F.						
Acetone.....	58.08	56.1	133	55.6 to 57.1	0.791-9	Pounds 6.61	° F. 14	Minutes 5.5	Miscible in all proportions.
Methanol.....	32.04	64.5	148.1	64 to 66	0.7924	6.59	60 (57.2)	6-8 (est.)	Do.
Ethanol—pure.....	46.07	78.3		77 to 80	0.7905	6.58	70 (67)	6-8 (est.)	Do.
95 percent.....		78.2		(76 to 79.5)					Do.
N-propyl alcohol.....	66.06	97.19	206.96		0.8110-812	6.76	75	6-8 (est.)	Do.
Iso-propyl (99.2).....	60.09	82.3	180.14	80 to 82.5	0.8044	6.70	70	50-55	Do.
N-Butanol.....	74.12	117.7	243.86	115 to 118	0.7862-93	6.54	115 (95)	67	20 (17-12).
					0.810-13	6.76			7.7 (8.9). <sup>3</sup>
Amyl alcohol.....				128 to 132	0.811-5	6.76	127	100	Slight.
Permentation grade-refined.....	88.09								
Synthetic (primary).....		137.9	280.3	134.5 to 138.5	0.817	6.83	136		Slight.
Fusel oil, refined.....				110 to 135	0.811-5	6.76	123	103.5	19.
Methyl ethyl ketone.....	72.06	79.6	175.28	77 to 81	0.806-10	6.72			30 (est.). <sup>3</sup>
									3.5.
Ethyl acetate.....	88.10	77.1	170.8	75 to 80	0.899-0.902	7.50	42	10.25	8.7. <sup>3</sup>
									1.2 (0.5). <sup>3</sup>
Butyl acetate.....	116.16	126.5	259.7	115 to 135	0.874-8	7.29	100 (82.4)	34.75	1.6.
Amyl acetate, technical.....	130.11	148 (pure)	298.4		0.859-63				
Amyl acetate, purified.....				110 to 150	0.879 (pure)	(7.22)	103	51.75	1.8.
Ethylene glycol.....	62.07	192.2	387	190 to 210	1.1150-8	9.28	240-260	Trace	Miscible in all proportions.

<sup>1</sup> Compiled from specifications of various manufacturers and other sources. These represent approximate values for commercial products. (Parenthetical values quoted by some manufacturers.)

<sup>2</sup> Amount of water dissolved by 100 parts of solvent.

<sup>3</sup> Parts of solvent dissolved by 100 parts of water (i. e., solubility extends both ways).

## ALCOHOL FOR SYNTHETIC RUBBER

A number of types of synthetic rubber can be produced. However, some of these are special-purpose types, manufactured in small quantities only. The most adaptable type, which is produced in the greatest quantity (around 90 percent of the total production) is an adaptation of the Buna rubber produced and used by the Germans during World War I, and is designated as GR-S in the United States.

The basic material for GR-S type synthetic rubber is butadiene, which is a gas at ordinary temperatures. Three parts of butadiene and one part of styrene or acrylonitrile can be combined (with additives) to make about five parts of commercial Buna-type rubber. Butadiene can be produced from alcohol by at least three methods, and it also can be produced from butylene glycol (also derivable from farm crops by fermentation methods), and from petroleum. Hence, instead of considering aspects of future alcohol use on the more complex basis of rubber production, it is sufficient to consider butadiene production. In the Government's program initiated during World War II, petroleum was originally intended as the source of practically 65 percent (based on rated plant capacities) of the butadiene needed for synthetic (GR-S) rubber. This was determined on the probability that butadiene could be produced more cheaply from petroleum than from alcohol, at usual raw material prices. Hence, only 3 of the 16 butadiene production plants were designed for operation on alcohol. However, a plant required for producing butadiene from petroleum is more expensive than one for producing it from alcohol, which reduces somewhat the initial raw material advantage of low-cost petroleum.

Alcohol-butadiene plants carried most of the load during the early production period, since development of the petroleum-butadiene sources met unexpected delays. A principal difficulty was that petroleum butylene, source of butadiene, also was needed for production of the high-octane gasoline required for military aircraft operation. In addition, construction of plants operating on petroleum was delayed, and certain operation difficulties had to be overcome. In the emergency, the alcohol-butadiene plants reached a production rate of 188 percent (37) of their rated capacity in August 1944, accounting for 82.3 percent of the total butadiene then produced. Eventually, most butadiene plants greatly exceeded their rated capacities. In 1944, 65 percent of all the butadiene produced was made from alcohol (36, pp 26, 51), the GR-S rubber production representing 668,879 long tons of the total synthetic (all types) rubber production of 737,131 tons. In 1945, alcohol accounted for only 40.5 percent of the total butadiene, owing to increased production from petroleum. Over the entire war period, alcohol butadiene represented 56.2 percent of the reported total production of 1,290,522 tons of butadiene.

Total synthetic rubber production reached an annual rate of 1 million tons in 1945, but actual production was only 801,921 long tons, owing to the ending of the war. Of this amount 717,688 long tons was GR-S type. In 1946, production decreased to 725,000 (estimated) tons, and in 1947 production in the latter part of the year fell to around 36,000 tons per month. By June 1948, production of GR-S rubber was at a rate of 400,000 tons annually, out of a total synthetic rubber production rate of 494,600 tons.

Total prewar world production of rubber (1937-39) was about 1.25 million tons annually, of which about 95 percent was natural rubber. The United States at that time was using approximately half of the world supply annually and the trend toward greater use was increasing. Natural rubber prices usually fluctuated between 12 and 24 cents per pound and averaged around 17 cents, although wide deviations occurred. Future United States rubber needs of perhaps 1 million tons per year are anticipated. If increased use by foreign nations also occurs, total world requirements may exceed total natural rubber production. A synthetic-rubber industry may be needed, therefore, to supplement natural-rubber sources, especially since present synthetic rubber has qualities often superior to natural rubber for certain uses. This is particularly true of the new cold-process type. Furthermore, since natural rubber is not grown in the United States, the existence of a synthetic industry to insure a continuing supply of rubber is essential to avoid another war emergency such as was experienced in 1941-45 when imports were cut off. World production of natural rubber was at the rate of 1,332,000 long tons for 1948 (4, pp. 82, 126, 132). Total United States consumption of all types of rubber for 1948 was at the rate of 1,376,700 tons, of which natural rubber and latex represented 636,000 tons, or about 46 percent of the national consumption. The United States total demands of natural rubber (1948) was about 48 percent of total world production.

Synthetic rubber production during 1947, under the Government program, was planned at about one-third of existing plant capacity (250,000 tons per year) but only petroleum sources (of butadiene) were utilized since it was the cheapest source, and increasing competition could be expected from natural rubber, obtainable abroad (1946) at around 22 cents per pound. In 1947 the price of natural rubber fell to 14 cents temporarily, owing to oversupply for current use, but later rebounded to 23½ cents. The price for synthetic rubber has been held constant by the Government at 18½ cents. Some of the surplus war-built Government synthetic rubber plants have been sold to private industry, but they remain available for use in emergencies, pursuant to the Rubber Act of 1948 (Public Law 469, 80th Congress).

Under this Rubber Act (Public Law 469, signed by the President March 31, 1948, and effective until July 1, 1950), a mandatory annual production of 200,000 long tons of general purpose and 22,000 tons of special purpose (butyl and acrylonitrile) synthetic rubber was ordered. A special agency within the Department of Commerce was set up to administer a program of production and use, and to maintain in operation or in stand-by condition the necessary facilities for producing 600,000 long tons of general and 65,000 tons of special synthetic rubber (3, pp. 247-250). This was primarily a defense measure, and was independent of the law (Public Law 520 of July 23, 1946) requiring stock piling of essential materials. The agency was given wide authority to supervise all national use of rubber, including natural rubber, and to set up percentages of use.

In 1948 the use of synthetic rubber in the United States was greater than the minimum quantities contemplated in the above enactment. It is significant that the law provided that at least one alcohol-butadiene facility be maintained, at least in stand-by condition. (Actually, two such plants have been held.) In 1948, a rated capacity of 162,000



long tons was allocated to the production of the new low-temperature synthetic rubber.

Butylene occurs as a normal constituent of the waste gases obtained in the refining and "cracking" of crude petroleum for gasoline, the percentage varying with the processing method and charging stock used. It can be produced in larger amounts by proper adjustment of processing factors. Butadiene is produced therefrom by a dehydrogenation reaction. Costs of producing butadiene from petroleum decreased in 1947 to around 6 to 7 cents per pound. If petroleum prices rise through approaching scarcity or other cause and alcohol prices decrease, alcohol may then achieve a more economic position as a butadiene source. The possibilities were stated by Rubber Director Bradley Dewey (1944) to be <sup>26</sup> (1, pp. 25-27) as follows:

Future natural raw rubber basic values may be as low as 12 to 15 cents per pound. Buna S rubber should be producible eventually at 14 cents per pound, excluding plant depreciation but including reasonable management fees. Costs for labor, chemicals, maintenance (excluding depreciation), supervision, utilities, management ( $\frac{1}{2}$  cent), and research ( $\frac{1}{4}$  cent), may total 4.5 cents per pound at capacity operation. With butadiene and styrene each bringing 8 cents per pound, f. o. b. copolymer plant, the cost of producing Buna S should be 12 cents per pound plus depreciation. A possible future reduction of 1 cent per pound is foreseen.

Since butadiene constitutes three-fourths of the mixture converted to Buna S rubber, the cost of the butadiene for 1 pound of Buna S on such basis is limited to three-fourths of 8 cents, or 6 cents. The cost of the 2.2 pounds of butadiene that can be made from a gallon of alcohol <sup>27</sup> will be the cost of the alcohol plus 2 cents per pound for processing charges. Alcohol at 12 cents a gallon (if obtainable at that price) would therefore entail a 7.5 cent butadiene cost (less possible byproduct credits from oils and gases now wasted). Alcohol at 15 cents per gallon would represent a butadiene cost of 8.8 cents. In the case of butadiene from petroleum, butylenes available at a wholesale gasoline price of 5 cents a gallon should yield butadiene at a cost of 7 cents per pound, with possibly 6 cents and not over 8 cents as extremes, excluding depreciation. The price of styrene may fall below 8 cents. Therefore, postwar Buna S rubber, excluding depreciation, may cost about 12 cents per pound at a minimum, or 14 cents at a more conservative estimate.

Based on best performances at Government-owned plants, the cost situation outlined above may be somewhat improved in the future, as shown in table 18. This table demonstrates the present price advantage of petroleum as a butadiene source, and indicates that alcohol must be produced very cheaply for effective competition.

Plant construction costs for the chemical constituents, per ton of rubber per year, are approximately \$79 for styrene, \$336 for butadiene, and \$151 for copolymer plant units for the lower-cost, larger plants of the rubber program. (Prewar plant construction costs would be perhaps 60 percent of these figures.) If this investment is charged off in 15 years, a depreciation charge of 1.05 cents per pound of Buna S is indicated. From the existing situation, it is possible that a postwar price for crude rubber of 16 cents or more per pound could meet prompt competition from the synthetic product (1).

Translating the butadiene costs to grain, on the basis of available information concerning alternate routes through alcohol as derived by different methods, data contained in table 19 can be derived.

<sup>26</sup> Supplementary report (36) for 1945 shows actual GR-S production cost for December 1945 was 16.2 cents.

<sup>27</sup> Yields increased to 2.6 pounds per gallon in 1945.

TABLE 18.—*Cost of producing a pound of GR-S rubber*<sup>1</sup>

Item	Cost of butadiene	Cost of styrene	Cost of conversion	Total cost
	<i>Cents</i>	<i>Cents</i>	<i>Cents</i>	<i>Cents</i>
1. Present average costs—all plants-----	23. 5	2. 2	5. 0	30. 7
2. Present cost at lowest cost project-----	4. 9	1. 4	4. 6	10. 9
3. Possible postwar cost, using alcohol as source of butadiene (styrene at 5 cents a pound).				
Alcohol at 90 cents per gallon (delivered) -	26. 2	1. 1	4. 5	31. 8
Alcohol at 50 cents per gallon (delivered) -	15. 2	1. 1	4. 5	20. 8
Alcohol at 30 cents per gallon (delivered) -	9. 8	1. 1	4. 5	15. 4
Alcohol at 25 cents per gallon (delivered) -	8. 5	1. 1	4. 5	14. 1
Alcohol at 20 cents per gallon (delivered) -	7. 2	1. 1	4. 5	12. 8
Alcohol at 15 cents per gallon (delivered) -	5. 8	1. 1	4. 5	11. 4
4. Possible postwar cost, using butylenes as butadiene source (styrene 5 cents a pound).				
Butylene at 10 cents per gallon-----	5. 1	1. 1	4. 5	10. 7
Butylene at 8 cents per gallon-----	4. 6	1. 1	4. 5	10. 2
Butylene at 6 cents per gallon-----	4. 2	1. 1	4. 5	9. 8
Butylene at 4 cents per gallon-----	3. 8	1. 1	4. 5	9. 4

<sup>1</sup> Report on the Rubber Program (1940-45) (37, p. 61). Later report (36) shows improvement of values, especially on alcohol butadiene.

TABLE 19.—*Estimated yields of butadiene from different sources and permissible cost of agricultural raw materials*

Intermediate and process	Butadiene		
	Per gallon of alcohol		Per bushel of corn
	Present	Anticipated	Equivalent
	<i>Pounds</i>	<i>Pounds</i>	<i>Pounds</i>
Alcohol, process A (using synthetic alcohol) -	2. 3	2. 5	6. 25
Alcohol, process B (using synthetic alcohol) -	2. 2	3. 0	7. 5

*Permissible cost of raw material*

Raw material; intermediate; assumed yields	Comparative raw material gross value based on obtainable butadiene yield at 6 cents per pound
Corn; alcohol; 2.5 gallons per bushel=6.25 pounds butadiene (process A).	37.5 cents per bushel of corn. <sup>1</sup>
Corn; alcohol; 2.5 gallons per bushel=7.8 pounds butadiene (process B).	46.7 cents per bushel of corn. <sup>1</sup>
Blackstrap molasses; alcohol; 0.4 gallon alcohol per gallon of molasses=1 pound butadiene (per gallon molasses).	6.0 cents per gallon of molasses. <sup>1</sup>
Blackstrap molasses (process A) after deducting alcohol processing cost, same basis.	±3. 6 cents per gallon of molasses.

<sup>1</sup> From these gross values the cost of producing the alcohol must be deducted.

That synthetic rubber cannot be made competitively from alcohol produced from grain at ordinary values, seems obvious from the data presented in table 19 and the accompanying tabulation. Grain costs seemingly would have to be as low as 18 to 25 cents per bushel, to be competitive, unless alcohol-production costs from grain can be reduced greatly. Bushel values as quoted in table 15 present little inducement to the farmer. In comparison, synthetic alcohol, alcohol from sulfite liquor or from waste wood or cellulosic agricultural wastes, as well as that from molasses, in all instances are or may be producible eventually at costs lower than from grain. Hence, this alcohol outlet seemingly does not present favorable opportunity for economic future use of surplus agricultural products, as has been advocated frequently, unless offsetting factors materialize. Grain costs above the economic base value presumably would have to be offset by taxation or some form of Government subsidy.

In any event, the production of synthetic rubber from farm crops is not likely to constitute a significantly large market for such crops, under normal conditions. One bushel of corn would represent about 8.7 pounds of rubber (via alcohol), or 258 bushels would be required for 1 long ton of rubber. The future over-all rubber demand may average around 1 million tons. Since natural rubber probably will be used to a great extent, and since other forms of synthetic rubber will be available, while the bulk of the GR-S synthetic product probably would be made from petroleum, the maximum anticipated production of such synthetic rubber from alcohol might not exceed 200,000 tons. This total amount would represent only about 52 million bushels of grain. Furthermore, it seems possible that rubber production from alcohol would be based largely on synthetic alcohol rather than on grain alcohol, because of price advantage, unless special legislation existed or subsidies were employed.

#### ALCOHOL FOR MOTOR FUEL

The possibility of using alcohol as a fuel for internal-combustion engines, particularly in airplanes, motor cars, and trucks has had public interest for several decades. In addition to technological aspects, factors relating to the national economy have become a part of the problem, as for example, the possibilities of conserving petroleum reserves or the utilization of surplus or wasted farm materials. Many comprehensive discussions of the economic significance have been published (22, 15), therefore, only a brief resume will be presented herein. The entire subject is being studied extensively at the Northern Regional Research Laboratory, Peoria.

Alcohol might be used to develop engine power as a *straight* fuel, as a *blend* with gasoline, or as an *extra* fuel injected by use of a special device during periods of heavy load to secure improvement in the functioning of the engine. In general, the first method seems least likely of application, owing to the relatively high cost of alcohol. Gasoline now sells at refineries (1949) for 8 to 11 cents per gallon (formerly 5 to 6 cents). A gallon of ordinary gasoline represents around 110,000 to 130,000 British thermal units, whereas, a gallon of alcohol might yield 78,474 British thermal units; therefore, alcohol as a straight fuel has only about 70 percent or less of the basic calorific



power of gasoline. Actually, alcohol may have a better relative position than thus indicated, since many other factors enter into engine functioning, but, at best, alcohol is more expensive. In the second instance, mixtures of small (5 to 10) percentages of alcohol with gasoline are more feasible since the net fuel cost is lower (approaching that of gasoline) and the gasoline may be improved, owing to increase of knock rating or octane number effected by the alcohol. Such mixtures or blends might yield engine performance (mileage, acceleration, etc.) relatively comparable to gasoline, under average conditions. Practically all the economic discussions assumed the use of such blends, until recently.

The third method may represent a further decreased fuel cost since the alcohol usually is employed in a mixture with water (50-50 up to 85-15), and is used only when additional engine power is required (take-off of airplanes; climbing hills, or accelerating speed of motor cars). Such fuel is carried in a separate tank and used automatically only as needed. This eliminates the necessity of using alcohol with all of the gasoline consumed, as in the case when both are used as a blend. This economy is possible because of recent realization that a high-octane fuel ordinarily is not required for car operation at light loads and low speeds, or on level terrain, unless relatively high cylinder compression is used. The relative total amounts of alcohol likely to be required in the United States, assuming that all cars were operated under the respective methods, would be greatest with alcohol as a straight fuel and least by alcohol-water injection. The Northern Regional Research Laboratory is studying alcohol-injection performance in test cars and tractors, and is experimenting with blended fuels in a specially designed motor-fuels testing laboratory.

Proposals for alcohol use as motor fuel stem from three basic considerations: (a) Possible future shortages of petroleum as a result of depletion of irreplaceable reserves by current rate of use, which eventually may necessitate the extensive production and use of substitute and more expensive liquid fuels; (b) possible recurrence of excessive surpluses of farm crops, entailing low crop price levels, or costly Government supports, and recognition of the constant annual losses represented by low-grade or wasted agricultural materials; and (c) former use of alcohol fuels in foreign countries which were or are deficient in petroleum resources. The programs in use in the last instance have varied from year to year in respective countries, and ordinarily have been uneconomic unless measured by standards of national defense or welfare. Since such programs at best were of make-shift character, discussion of this phase is omitted herein. Present arguments for alcohol fuel use usually embrace considerations (a) and (b) simultaneously, hence pertinent data on each are presented in the sections that follow.

### PETROLEUM SUPPLIES AND POTENTIAL SUBSTITUTES

The extent of our below-ground petroleum reserves has been a matter of controversy. Consumption has increased greatly, over pre-war years, the rate for 1948 being 5.6 million barrels, or 235 million gallons of crude petroleum per day, while discovery of new oil fields has fallen off. Estimates of so-called proven reserves meanwhile have

been amended from about 12 billion barrels in 1935, to 23 billion barrels (January 1, 1948), despite annual withdrawals averaging about 1.7 billion barrels during that period. In 1948 withdrawal rates had risen to 2 billion barrels annually, yet the estimated reserves have increased to 24.8 billion barrels as of January 1949. This increase of the reserve estimate has been achieved largely by frequent recalculation of the potential withdrawals of oil from the ground (to amounts believed to be possible with improved operation), since new oil pool discoveries have averaged only about a half billion barrels annually, in recent years, and dropped to 209 million in 1948.

Trends indicate a possible future utilization rate of 7 million barrels daily. However, new oil is becoming more expensive to discover and produce. Wells are being driven to deeper levels, and a larger percentage of drillings are dry holes. Hence, the cost of replacing the oil currently being used is increasing annually. As underground supply diminishes, the rate of flow will decrease so that, long before the reserves are entirely depleted, oil recovery costs will have increased and production rate diminished.

While there are now approximately 4,000 producing fields in this country, about 48 percent of the oil production comes from 111 major fields that contain about 60 percent of the estimated total reserves. Therefore, the flow from large fields (of 100 million barrels each) must be sustained if daily production is to be sustained at present levels. This means that new major fields must be discovered as rapidly as the older ones decline in productivity. In the period 1940-47 only eight major fields of such size were discovered. If this rate is not increased, prospects for increasing our present production level are not encouraging.

At present, 68 percent of the known world supply of petroleum is located outside the United States according to J. E. Pogue (18, p. 59); eventually the United States may have only 10 percent of the total supply. Meanwhile, besides being a relatively ideal fuel and a first line of defense, petroleum also is becoming a chemical raw material or source of new compounds (24, pp. 136, 140) (dyestuffs, insecticides, textile finishes, solvents, adhesives, paints, pharmaceuticals, etc.). The use of oil for fuel also has increased greatly. Therefore, the development of a new supply source of liquid fuel seems imperative. Apparently, about 2 million barrels per day must be obtained from sources other than domestic petroleum, to meet the future demands. Creation of such amounts of fuel by synthesis will constitute a vast undertaking.

Chief liquid fuel replacement sources now in sight are: (a) Imported petroleum; and synthetic products from (b) natural gas (46, pp. 1244-49) or from waste petroleum or other gases; (c) coal gases (32); (d) hydrogenation products from coal (32); (e) shale oil from shale rock; (f) oil from tar sands; and (g) alcohol or other chemical compounds producible from vegetation (carbohydrates). In every instance direct or indirect consumption of irreplaceable natural reserves is indicated. In the case of alcohol derived from annually renewable agricultural materials, the interaction of sunshine, air, water, and soil is utilized, of which only the soil is depleted. Since such soil can be restored almost continually, this source represents, therefore, a less serious drain on national mineral resources, principally

for the fuel necessary for processing. Such advantage of easy supply might outweigh the nominal unit-cost advantage of present materials, from a national standpoint, particularly if the opportunity thus afforded for utilizing excess farm materials to benefit agricultural economy is suitably developed.

The development of any synthetic-fuel industry will entail a large investment in plants for producing such materials, since such facilities do not yet exist. Consumption of gasoline (taxed for highway use) currently is around 28 billion gallons per year. It would require 2.8 billion gallons of alcohol annually, therefore, to convert all this consumption to a 10 percent alcohol-gasoline blend basis. This might be considered as equivalent to perhaps 150 million barrels of original crude petroleum, and would necessitate construction of 700 alcohol plants of 4 million gallons annual productive capacity, or equivalent larger plants, representing perhaps 700 million dollars capital investment. However, even such investment seemingly is less than what would be required to produce equivalent amounts of fuel from coal, shale oil, or gas.

Since excess alcohol manufacturing capacity exists, over ordinary commercial needs, it might be possible to produce upward of 300 million gallons annually from existing plants, as a quick-start on any program. A further annual investment might be necessary to equalize the costs of bringing alcohol from grain into proper cost relationship with gasoline.

Published estimates vary widely but Lane and Weil (16, pp. 587-598) indicate that it may require an investment of at least \$2,500 to \$4,000 per daily barrel of liquid synthetic petroleum production from natural gas. Investment for a plant using gasified coal may run from \$9,000 to \$10,000 (20, pp. 574-577) on such basis.

Since only part of such crude product would be gasoline, the production of only 10 percent of the present total national annual gasoline consumption ( $\pm 70$  million barrels) would require the investment of perhaps 4 billion dollars and the building of many plants. The Hydrocol plant (capacity 5,800 barrels of gasoline per day, or 89 million gallons per year, plus 1,200 barrels of Diesel fuel) now under erection originally was expected to cost 19 million dollars (1), but under present conditions the cost may be doubled. This plant will require 64 million cubic feet of natural gas, plus 40 million cubic feet (or 1,760 tons) of oxygen per day.

On such basis the production of a mere 10 percent of our present gasoline consumption would require about 32 similar plants and a consumption of about 2 billion cubic feet of gas per day. Production of all the gasoline now used thus would cut into natural gas reserves at the rate of 7.3 trillion cubic feet annually, or one and one-half times our present consumption of gas for all purposes. Total natural gas reserves are now estimated at about 160 trillion cubic feet (1947).

To produce 100 barrels of synthetic fuel from coal by hydrogenation requires about 65 tons of coal. Production of 1 million barrels per day (one-fifth of present total petroleum requirements) would require 650,000 tons of coal per day or 237 million tons per year. The entire coal production in 1941 was 511 million tons, hence the production of all our present liquid fuel from coal would require more than twice



the entire quantity of coal mined in 1941, and leave no coal production for other purposes. According to Dr. Bruce K. Brown (9, pp. 190, 376) the production of 10 percent of our present gasoline consumption from coal seemingly would require an investment of 2.5 billion dollars. The cost of compressed hydrogen represents about 50 percent of the total cost of the oil. Plant costs are estimated at 400 million dollars for 50,000 barrels of crude oil per day.

The situation as to production from shale oil is in the same category, when the handling of the vast amounts of shale and spent rock are considered. In each of the foregoing instances plants for the entire industry would have to be constructed (9). Present data (20, pp. 574-577) indicate that shale-oil plants will require an investment of about \$2,000 per daily barrel (42 gallons) output of crude oil. Estimates of the cost of the crude oil range from \$1.75 to \$2.75 per barrel. Paraffin waxes, tar acids, etc., are recoverable as byproducts. About 30 gallons of oil can be obtained from a ton of average Colorado shale, though various shales will contain from 15 to 80 gallons per ton. Cost of mining may run 50 to 60 cents per ton. Present indications are that refined shale oil is more suitable for Diesel engine fuel than for motor car operation. Quality of the oil may perhaps be improved by hydrogenation, since the hydrocarbons present are largely olefinic.

It appears evident, therefore, that any liquid-fuel production program will be extremely expensive and require a long development period, regardless of the degree of accuracy of the predictions. Importation of petroleum may be the least expensive method of extending present reserves, but it has the serious objection of possible interruption of supply in time of war. Use of alcohol as a partial source of motor fuel seems to merit consideration—provided that raw materials are available in sufficient quantity and at commensurate cost.

#### AGRICULTURAL ASPECTS

Alcohol production for fuel purposes seemingly would have to come from agricultural sources and involve fermentation processes. Such production probably would be based largely on the cereal crops, although certain other crops (fruits, beets, potatoes) might find some utilization at times. Certain culls, wastes, or low-grade materials might be used also to a lesser and uncertain extent. The program might be set up merely as a scavenger-type industry, producing such amounts of alcohol as might be obtainable from surplus or wasting crops from year to year, or it might visualize the growing of crops specifically for industrial use, or some combination of the two methods. At present rates of crop production only a portion of the vast quantity of alcohol that would be needed for a large-scale alcohol-fuel program could be provided. Some extension of present crop acreages may be possible, but limitations exist.

Under the former normal agricultural production and marketing situation, some crops at times were produced in excess amounts, resulting in a surplus which disturbed the price structure. The result usually was a loss to the farmer—either directly on the unsold amounts or indirectly through the depressed market price—this being particularly true if the crop was perishable. If the crop was relatively non-perishable, the hold-over surplus, if large, affected the market in sub-

sequent years. Under present price support programs the fluctuation in supply, or production of excess amounts still continues, but the expense and losses largely are transferred from the individual farmer to the Government. The same factors continue to exist. Also, in average as well as in bumper crop years, accumulations of culls of certain crops occur at sorting or shipping points and these, as well as the crop surpluses, should have some method of economic utilization. Because of the large potential amounts involved, the motor fuel outlet seems to be the one possible industrial use that in normal times might be able to absorb these materials, if prices were properly adjusted. The whole problem is as much economic as technical.

Some idea of the magnitude of the fuel-alcohol problem is shown by the following estimates: Assuming that 15 percent of any carbohydrate food crop normally represents culls, surplus, and waste which might become available, and that it were possible to collect and process successfully all this material, the alcohol obtainable from all the grain, fruit, and other carbohydrate crop surpluses and wastes (22 crops in 1935, as representing a normal year) may be estimated as about 1,650,000,000 gallons. Therefore, the alcohol potentially produced from such vast amounts of raw material would represent only about 6 percent of the volume of gasoline used throughout the country as motor fuel.

As far as industrial crops are concerned, if corn alone were used as raw material, for example, approximately 1 billion bushels, or more than one-third of a normal crop, would be required to make the alcohol necessary for replacing one-tenth of the gasoline annually used. The replacement of all the gasoline by alcohol is at present inconceivable.

The production of alcohol from farm products, therefore, might have as objectives either (1) the recovery of all possible values from materials not economically utilized at present, or (2) the stabilization of crop prices. Approached from a basis of an alcohol program for the benefit of agriculture only, it appears that the production of alcohol in large quantities would not be necessary to attain program results. Particularly, crop price stabilization might be achieved by mere removal of cash grain surpluses, which usually might average perhaps 300 million bushels for any particular cereal crop.

The production of alcohol for motor fuel use from a variety of farm crops would entail the problem of equalization of alcohol costs, since these costs would be different for every raw material. This use would be further complicated by the geographical locations of such surplus farm products.

Any industrial use of crops necessarily would have to be based on continued ample supplies and stable price levels. Since the alcohol produced undoubtedly would have to sell at a common price which did not fluctuate to an unreasonable extent, it seems obvious that any such program could be dealt with effectually only by a comprehensive program integrated to national agricultural situations. Therefore, control of the whole program logically should best be centered in an appropriate agency of the Government. While minor alcohol production by independent groups might be effective in utilizing the surpluses and culls of and in a particular local area, any such attempt of significant size would immediately come into competition with the commercial production of alcohol and the prevailing

price levels. Alcohol production on a relatively local scale would be faced with high transportation charges on raw material if the area extends too far from a central point. This would be emphasized particularly in the case of cull materials and would constitute a limitation on the possible size of such independent operations.

The present commercial production of ethyl alcohol from standard sources such as molasses and grain, or by synthesis, sets a competitive price standard which must be met, ordinarily. Crop culls and wastes usually constitute poorer materials that are relatively unsalable under usual market conditions. Such material may be relatively low in carbohydrate content, and it may contain dirt, excess moisture, fungi (molds), etc. The cost of the alcohol produced from such sources may be expected to be correspondingly high.

Many of the possible cull materials are highly perishable and will be lost unless processed with reasonable speed. Moreover, the available quantities vary from year to year. A program of alcohol production from these materials involves the maintenance of alcohol plants and personnel at central points, and such plants must have enough available raw materials to assure year-round operation for every year. It is not economical to build expensive alcohol plants and then depend on sporadic operation as local cull materials become available. It would be difficult for such plants to maintain adequate technical supervision without incurring relatively high per-gallon costs.

The setting up of a mere sort of scavenger industry—to make indeterminate and varying amounts of alcohol sporadically from such cull materials as may become available, for the manufacture of blended fuels of nonstandard quality—is not likely to yield results satisfactory to the agricultural program or to the motoring public.

In general, the use of farm products at food prices, in industrial uses, involves excessive costs. The ideal program would utilize culls and low-grade materials, close to their source, at industrial raw material values, leaving the high-grade portions of the crop available for food use.

As an approach to a study of the agricultural problems thus presented, the Bureau of Agricultural and Industrial Chemistry has maintained the previously described small experimental alcohol plant at Peoria. Under a Congressional enactment, signed by the President on July 2, 1948 (Public Law 890), the three Government-owned grain alcohol plants located at Muscatine, Iowa, Omaha, Nebr., and Kansas City, Mo., have been placed under the authority of the United States Department of Agriculture. The Department is authorized to use such plants for the disposal of crop surpluses, or for experimental studies on surplus utilization.

Any large and continuing exportation of American crops may preclude the possibility of developing a sound or extensive alcohol motor fuel program during such period.



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### SOURCES OF ADDITIONAL INFORMATION

The following section has been included because of frequent inquiries received in past years for this type of information.

#### MANUFACTURERS OF FERMENTING, DISTILLING, AND FEED-RECOVERY EQUIPMENT

E. B. Badger & Sons Co., Boston, Mass.	Atlas Copper and Brass Mfg. Co., Chicago, Ill.
S. D. Hicks & Sons Co., Hyde Park, Boston, Mass.	Chicago Bridge and Iron Co., Chicago, Ill.
The Lummus Company, New York, N. Y.	J. P. Devine Mfg. Co., Mt. Vernon, Ill.
Theo. Walter Copper Works, Inc., Newark, N. J.	Oscar Krenz Copper and Brass Works, San Francisco, Calif.
Acme Copper-smithing and Machine Co., Oreland, Pa.	Louisville Dryer Corporation, Louisville, Ky.
Blaw-Knox Co., Pittsburgh, Pa., and Bufllovak Equipment Division, Buffalo, N. Y.	Davenport Foundry and Machine Co., Davenport, Iowa
Vulcan Copper and Supply Co., Cincinnati, Ohio	Adt Dryer Corporation, Baltimore, Md.
Ansonia Copper and Iron Works, Inc., Cincinnati, Ohio	Swenson Evaporator Co., Harvey, Ill.
	Goslin-Birmingham Mfg. Co., Birmingham, Ala.
	U. S. Pipe and Foundry Co., Burlington, N. J.

Some firms normally will undertake to furnish complete plant installations; others specialize on certain types of equipment.

In listing the names of these firms no guaranty is implied, nor is it to be understood that these firms are recommended over others who may be engaged in the same line of business but whose names are not listed. The names have been obtained from commercial registers of manufacturers, or other sources, for the information and assistance of correspondents. However, much of the equipment now in use in the distillation industries originated from firms listed.



## PRICES

Current prices of industrial alcohol, blackstrap molasses, and other alcohols or chemicals: Chemical Industries, published monthly by Chemical Markets, Inc., Pittsfield, Mass.; Oil, Paint and Drug Reporter, published weekly by Schnell Publishing Co., Inc., New York, N. Y.; Chemical and Engineering News, published biweekly by the American Chemical Society, Washington, D. C.; and other trade journals.

## DISTILLERS' STILLAGE AS FEEDS

Many State experiment stations have issued bulletins on stock feeding. The Illinois, Iowa, Kentucky, Nebraska, and Ohio stations particularly might be consulted. Reports of the annual meetings of the Distillers' Feed Research Council, Inc., Cincinnati, Ohio, contain much specific information.

## PATENTS

The United States Patent Office, Washington 25, D. C., will supply copies of specifications for United States patents at 25 cents each, and information in regard to the procedure in obtaining copies of any foreign patents covering processes for the manufacture of alcohol from various raw materials. Some libraries maintain files of the more important patents on various subjects, which may be consulted.

## LITERATURE

Data on various aspects of alcohol production or use ordinarily may be obtained from any well-equipped library. The following sources are suggested, although these include only a small part of the informational literature existing. Further sources also are indicated in the literature cited in the text of this publication.

Government publications may be purchased from the Superintendent of Documents, Washington, D. C., if supplies are not exhausted.<sup>28</sup> Prepayment is required and should be made in cash (exact amount) or by postal or express money order payable to the Superintendent of Documents. Many libraries maintain files of bulletins, patents, and lists of publications and other Government releases.

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